MEDICAL ELECTRICITY

LEWIS'S PRACTICAL SERIES

LEWIS JONES

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A

PRACTICAL HANDBOOK

FOR

STUDENTS AND PRACTITIONERS

BY

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BEING THE SECOND EDITION OF "MEDICAL ELECTRICITY," BY
W. E. STEAVENSON, M.D., AND H. LEWIS JONES, M.D.

WITH ILLUSTRATIONS

LONDON
H. K. LEWIS, 136 GOWER STREET, W.C.
1895

PRINTED BY
H. K. LEWIS, 136 GOWER STREET
LONDON, W.C.

PREFACE TO THE SECOND EDITION.

The reception accorded to the first edition of this book has been so favourable, that it encourages the hope that in time the value of electricity as a mode of treatment may become more widely appreciated in this country.

At present medical electricity occupies a humbler position in applied therapeutics than it deserves.

The difficulties connected with the management of the apparatus, and a certain want of general knowledge as to what can and what cannot be done by electrical treatment still cause some to shut their eyes to the whole subject, or else to look at it with coldness. Others have condemned it because it will not work miracles.

When electrical treatment becomes familiar to medical practitioners the abuses which have surrounded it will disappear.

The progress which Medical Electricity is making is remarkable. In France there are two monthly journals dealing exclusively with this subject. In America there is an energetic Electro-therapeutical Association. In England, however, general interest in the subject is not yet aroused. In the year 1894 in a list of three hundred and sixty papers and publications on subjects connected with medical electricity I can find barely a dozen from Great Britain.

In the present edition the general plan of the last has been retained, with slight modifications. The early chapters have been simplified, and it is hoped that this

part of the book may be found useful, if only as a glossary to explain the technical words and phrases which are necessary in the more strictly medical parts. Instead of the words Galvanism, Faradism, Franklinism, the phrases "treatment by the battery," "by the induction coil," and "by the electrostatic machine" are used throughout the volume.

Those who wish to go more deeply into the study of the subject will probably find what they want in some of the following books, my indebtedness to which I now beg to acknowledge.

Ayrton, *Practical Electricity;* Silvanus Thompson, *Elementary Lessons in Electricity;* Oliver Lodge, *Modern Views of Electricity;* Fleming, *The Alternate Current Transformer;* Boudet de Pâris, *Electricité Médicale;* Duchenne, *Electrisation localisée;* Erb, *Electro-therapeutics;* Onimus and Legros, *Electricité Médicalé;* R. Remak, *Galvanotherapie.*

For the current literature of the subject, the monthly *Archives d'Électricité Médicale* is valuable, both for its original matter, for the abstracts, and for the bibliographical index published quarterly therein.

H. LEWIS JONES.

9 Upper Wimpole Street, W.
July, 1895.

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ERRATA.

Page 23, *line* 15, *for* "Brittanica" *read* "Britannica."

Page 157, *Fig.* 54, *for* "Suspended condition" *read* "Suspended conductors."

MEDICAL ELECTRICITY.

CHAPTER I.

Historical.

Origin of the word Electricity. Dr. Gilbert of Colchester. Early medical writers. First appearance in hospital practice. Faraday and Duchenne. Position of electricity in medicine. Influence of physical conditions on health. Atmospheric electricity.

1. **Origin of the word Electricity.**—The foundation of the modern science of electricity may be considered to have been laid by a medical man, Dr. Gilbert of Colchester, Physician in Ordinary to Queen Elizabeth and President of the Royal College of Physicians in the year 1600, the date of the publication of his treatise *De Magnete*. A copy of this work is in the library of the Royal College of Physicians of London, and a reprint is now being prepared under the direction of the Gilbert Club. In it he extended to a large number of other substances the ancient observation that rubbed amber attracted light bodies. It seems also that we owe to him the word Electricity, for he called all those substances Electrics, which when rubbed displayed the same attractive power for light bodies as amber (ἤλεκτρον, electrum) does, and soon afterwards the word electricity was introduced to indicate this power considered as a quantity capable of measurement.

2. **Dr. Gilbert of Colchester.**—Dr. Gilbert does not seem to have attempted to apply his knowledge of electricity in any way to medicine, but he will always

be remembered as the pioneer who made the first step towards the scientific investigation of what is perhaps the most wonderful agent that modern science has rendered obedient to the will of man. Dryden has immortalised him in the following lines :—

> "Gilbert shall live till lodestones cease to draw
> And British fleets the boundless ocean awe."

Another tradition connected with electricity which may be worthy of mention for its interest to the medical profession, is that a Mr. Davy, who recently died in Australia, is said to have transmitted a message by means of a wire from one part of St. Bartholomew's hospital to another, at the time when he was House Surgeon there, before the time of the invention of the Electric Telegraph.*

3. **Early medical writers.**—It was more than a hundred years after Gilbert's time that electricity was first brought into use as a curative agent. Jallabert in France, and De Haen in Germany, were among the first to employ it, in the early part of the last century. In this country it chiefly remained in the hands of non-professional men, but John Freke, F.R.S., Surgeon to St. Bartholomew's Hospital, wrote on it in 1702.

In 1759 the Rev. John Wesley, the famous divine, collected a number of cases in which electricity had been tried, and published them in a treatise entitled *The Desideratum, or Electricity made Plain and Useful, by a Lover of Mankind and Common Sense.*† In this treatise Wesley mentions Freke.

4. **First appearance in London Hospitals.**—

* For an account of Edward Davy's investigations see J. J. Fahie, *A History of Electric Telegraphy to the Year* 1837.

† This treatise was republished by Messrs. Bailliere, Tindall & Cox, London, 1871.

The first records of electrical treatment at a London hospital seem to have been in the year 1767, when an electrical apparatus was ordered for the Middlesex Hospital.* And ten years later, in 1777, an electrical machine was purchased for the use of the patients in St Bartholomew's Hospital. According to Dr. Church's interesting article in vol. xxii. of the St. Bartholomew's Hospital Reports on *Our Hospital Pharmacopœia*, it would appear that in 1818: "The electrical machine—whether the original one purchased in 1777 or not, I know not—being out of order, was placed under the care of the apothecary, who was directed to employ Mr. Blunt, of Cornhill, when it needed repair. Whether Mr. Blunt declined, or was unable to repair the machine, does not appear, but in the following year Mr. Latchford's report is entered in the minutes:—

" 'That the electrical machine at present in use was quite unfit to be repaired. It was proposed by him to make a new machine upon the modern principle, with a plate two feet in diameter, and all the apparatus and case complete to the satisfaction of the medical officers, and afterwards to keep the whole in good and constant repair for a sum not exceeding £17 18*s*., and that the machine be afterwards placed under the care of Mr. Latchford, but not to be taken out of the Hospital, and that Mr. Latchford will attend and electrify all the patients denoted by the medical officers to undergo the operation upon the following terms: if the operations within the hospital do not exceed thirty, at 2*s*. each, and if above that number, 1*s*. each. Resolved that the above conditions are approved of, and that the same be carried into effect without delay.'

* Erasmus Wilson, *History of Middlesex Hospital*, Churchill, 1845, p. 225.

"How long Mr. Latchford performed these duties, and whether he had a successor, I have been unable to find out. In 1838 he petitions for the second time that he should be paid by salary instead of the above terms. No answer to this petition occurs on the minutes, and no further mention of Mr. Latchford is found.

"In November 1843 Mrs. Woodcock's bequest of £200 consols to the Electrical Institution in Bunhill Row was made over by the executor of her will to the Hospital, as the institution to which she had bequeathed this sum had been dissolved during her lifetime. We see here the dawn of our present admirably arranged Electrical Department, which, however, took upwards of sixty years to blossom to its present perfection."

Electrical departments have at different times been established in connection with other London hospitals. One of the oldest is that of Guy's hospital. A letter on the subject of medical electricity by Mr. John Birch, Surgeon, is to be found in a book called *An Essay on Electricity*, by John Adams. The fifth edition of this book was published in 1799. Birch's letter occupies fifty pages. He was attached to St. Thomas's Hospital, where he was apparently in charge of the electrical department. Accounts of cases were published in the *Guy's Hospital Reports* by Addison,* Golding Bird,† and Sir William Gull,‡ in which the use of frictional electricity was followed by satisfactory results.

Among the first, if not actually the first treatise published by an English medical man upon the employment of electricity in medicine, was one written in Latin

* *Guy's Hospital Reports*, 1837, No. 2.

† *Ibid.*, vol. vi., 1841.

‡ *Ibid.*, 2nd series, vol. viii., 1852-53.

by Dr. Robert Steavenson,* of Newcastle-on-Tyne, for some years physician to the infirmary of that town, and great uncle to the late Dr. W. E. Steavenson.

5. **Faraday and Duchenne.**—In 1831 Faraday made his discoveries of electro-magnetic induction, and began the publication of that splendid series of researches which more than anything else have led to our present state of knowledge of the subject. They have made the applications of electricity a necessity of our civilisation. We must notice Faraday particularly here, since from his researches sprang the induction coil, which is used in the production of the induced or so-called *Faradic* currents so much employed in medicine.

The great champion of the value of induced currents in medical treatment was Duchenne, of Boulogne, and to him we owe the enunciation of the truth that for curative effects it is necessary that the currents should be localised, that is, applied directly to the parts which it is wished to influence; Duchenne also showed that the muscles could be more easily excited at certain points of the surface, which he called *points d'election.* These have since been proved by R. Remak and Von Ziemssen to be the places nearest to which the motor nerves enter the muscles. They are now called "the motor points" (Chap. VI.).

About 1850 great advances were made in our knowledge of electro-physiology. Du Bois Reymond and Pflüger demonstrated the electrical phenomena of living nerve and muscle, and established the laws of electrotonus and of muscular contractions, and the existence of muscle currents. Remak discovered the catalytic

* *Dissertatio Medica Inauguralis, de Electricitate et Operatione ejus in Morbis Curandis*, Robertus Steavenson, A. M. Britannus, Edinburgi, MDCCLXXVIII.

effects of the galvanic current and its influence on osmosis. Our present modes of application of electricity as an aid to diagnosis, has resulted from the investigations of Duchenne, Remak, Brenner, Erb, Von Ziemssen, Boudet de Pâris, Onimus, De Watteville, and many others of note.

6. **Position of electricity in medicine.**—The employment of electricity in medicine has passed through many vicissitudes, being at one time recognised and employed at the hospitals, and then again being neglected and left for the most part in the hands of ignorant persons, who continue to perpetrate the grossest impositions on the public in the name of electricity.* As each fresh important discovery in electrical science has been reached, men's minds have been turned anew to the subject, and interest in its therapeutic properties has been stimulated. Then after extravagant hopes and promises of cure, there have followed failures and disappointments, which have thrown the employment of this agent into disrepute, to be again, after a time, revived and brought into popular favour. During the long period of two hundred years in which these alterations have been taking place in the opinions held of the value of electrical treatment, and in the frequency of its employment, scientific men have been steadily pursuing their investigations into its wonderful properties and possibilities. Discovery on discovery has rewarded their patience, and we have now arrived at an age when the practical applications of electricity are making the most rapid strides. Medical thought and experi-

* This was not always so. Mr. John Birch, 1799, speaking of simple electrical experiments says, "They would have formed a grand basis for empiricism, if they had been artfully employed, but, as electricity has escaped abuses, I submit . . . . "

ment are moving in the same direction, and another wave of electro-therapeutics is passing over the profession. During the last ten years electrical departments have been re-organised at several of our hospitals, and the powers of electricity have been more and more called in to the aid of the physician and surgeon, and a general desire has been evinced both by members of the profession and by the public, for a more thorough knowledge of the benefits to be derived from this agent and of the best means of securing them.

7. **Influence of physical conditions on health.**—All physicians recognise the influence exerted upon health and disease by heat, light, and motion in the form of exercise, but very little attention has been paid to the place which electricity occupies in regulating the action of the vital processes. No doubt it has an influence upon the maintenance of health and the production of disease. We have now more accurate means of measuring electricity, and a more perfect knowledge of its action, and although much has still to be learnt under this head, we are altogether in a far better position for employing its effects in the treatment of disease.

The influence of physical phenomena upon the conditions of health and disease has long been recognised; the effect of bright fine weather upon one's feelings of health, and the depressing influence of gloomy weather are remarkable, and would excite great interest were the matter not so common as to pass unnoticed. We know that the humidity of a locality as affected by the subsoil drainage, has a great influence upon the prevalence of phthisis; that the barometric pressure influences the blood pressure; that electrical changes in the atmosphere, as on the approach of a thunderstorm, strongly influence many persons possessed of delicately

strung nerves; that sound, in the form of music, has also an influence upon the system, though how this effect of music is produced we do not at present understand. We are told that the varying vibrations of the ether which produce light of different colours are of use in the treatment of the insane. How these several influences act we are not as yet able to explain. The difference produced in highly sensitive or nervous people by sudden and marked changes in the weather, especially by the sudden fluctuations of temperature to which our climate is so liable, may be partly due to the electrical changes set up thereby.

There are reasons for believing that the electrical conditions of the atmosphere influence health. This much at least seems to be certain, that differences in the electrical condition of the earth take place, and are continually taking place, and that a highly sensitive organism, such as the human body, must participate and take cognizance of these changes; it is not then too much to suppose that these changes have some influence upon health. All conditions of the atmosphere which have been noticed to influence health prejudicially, are said to be accompanied by an increase in the amount of the negative electrification of the atmosphere, as indicated by an electrometer. Before a thunderstorm, when people of a delicate nervous temperament assert that they feel indescribable "malaise" and oppression, the atmosphere in the neighbourhood of the earth is negatively electrified.

8. **Atmospheric Electricity.**—The phenomena of atmospheric electricity have not been much studied for their effect upon health, but it is quite certain that there may be very decided electrification of human beings by means of atmospheric or rather of the terrestrial electricity.

Observations show that the surface of the earth is negatively charged, while the upper air is charged positively; the lower regions of the air when dry act as an insulating space between; and may be compared to the glass of a charged Leyden jar.* If we could measure the electric potential at different points within the thickness of the glass of a Leyden jar, we should find that the values of the potential changed in a regular order from a + value on one side to a − value on the other, there being a point of zero potential at some point between the two. The so-called measurements of "atmospheric electricity" are really measurements of difference of potential between a point on the earth's surface, and a point somewhere in the air above it. The air in fine weather always gives positive indications, and the potential of it is higher, the higher we go to measure it. On one occasion Sir Wm. Thomson found the potential in the Island of Arran to increase by 430 volts in a rise of nine feet, but the difference of potential for the same difference of level may vary very much and very rapidly.

When there is a very great rise of potential for a small difference in level, luminous phenomena of the nature of a brush discharge may be observed, such as St. Elmo's fire on the tops of ships' masts, the luminous points upon the spears of the Roman soldiers recorded in Livy. Such luminous phenomena have several times been noticed by observers upon mountain tops, notably of late years upon Ben Nevis. Here the mountain and the observer are to be regarded as conductors at the potential of the earth's surface which project into a stratum of air of a widely different potential, and the brush discharge is due to a leakage current, tending to equalize the difference of potential.

* S. P. Thompson, *Elementary Lessons on Electricity.*

It is therefore reasonable to consider a human being standing in an upright position in an open place as a conductor, charged to the potential of the earth's surface and projecting into an electrically charged field of a different potential, the difference of potential being greatest between his head (the highest part of his body) and the air at the corresponding level.

When the observer stands upon any lofty eminence the difference of potential between himself and the surrounding air is naturally greater than when he stands upon level ground, and the reverse is the case for a person in doors, in narrow streets or under trees; then there is little or no difference of potential between himself and his surroundings.

CHAPTER II.

PHYSICAL CONSIDERATIONS.

Division of the Subject. Fundamental Experiments. Hypotheses of Fluids. Electrics and Non-Electrics. Electroscopes. Conduction. Electric Quantity. Electro-motive Force, potential. Physical Analogies. Electrometers. Electric Density. Action of Points. Capacity. Condensers. Leyden Jar. Contact electromotive force. Simple Voltaic cell or battery. Oersted's experiment. Magnetism. Magnetic field. Galvanometers. Electromotive force. Resistance. Ohm's law. Practical units. Specific resistance. Measurement of resistance. Electrolysis. Anode and Kathode. Laws of electrolysis. Electro-chemical equivalents. Resistance of an electrolyte. Electro-magnetic induction.

9. **Division of the subject.**—It is usual for medical men to speak of electrical effects as if they were due to no less than three distinct kinds of Electricity. These we are accustomed to call "Frictional or Franklinic Electricity," "the Continuous or Galvanic Current," and "the Interrupted or Faradic Current." This division, however convenient it may be for purposes of medical treatment, has not even convenience to recommend it when the subject is looked at from a scientific point of view, and is certainly most incorrect. The Science of Electricity may best be divided into four branches as suggested by Dr. Oliver J. Lodge in his interesting book *Modern Views of Electricity*, a book which should be read with great care by everyone who wishes to have definite and correct notions concerning the science. These four divisions are :—

a. Electricity at Rest, or Static Electricity.—This branch coincides with that portion of the science generally treated of as "Frictional" Electricity.

b. Electricity in Locomotion, or Current Electricity.—This includes the consideration of the continuous current and of the interrupted current.

c. Electricity in Rotation or Magnetism.

d. Electricity in Vibration or Radiation, a branch of the subject treated of in general under the heading of Light.

We only need to consider at all fully the two first of these branches, and of these more especially the second. The fourth branch we need not consider at all, while we shall have to make a few remarks about magnetism in order to make clear the nature and principles of certain electrical measuring instruments.

10. **Fundamental Experiments.***—If a piece of glass and a piece of resin be taken they neither attract each other nor any light bodies to which they may be presented. If now they be rubbed together, so long as they are not separated, they still display no powers of attracting light bodies, but let them be separated and they are at once seen to be endowed with the power of attracting each other, and each is capable of attracting light bodies. They are said to be electrified. If a second pair of pieces of resin and glass be taken, rubbed together and then separated, it may be seen—

a. That the two pieces of glass repel each other.

b. That each piece of glass attracts each piece of resin.

c. That the two pieces of resin repel each other.

The two pieces of glass are said to be oppositely

* *On the Mathematical Theory of Electricity in Equilibrium.* Sir W. Thomson's papers on *Electro-Statics and Magnetism*, p. 43. Maxwell's *Electricity and Magnetism*, vol. i., p. 31.

electrified to the two pieces of resin, and we can observe as a definition that similarly electrified bodies repel each other, oppositely electrified bodies attract each other. These electrifications are known as *vitreous* or *positive* and *resinous* or *negative*. We also observe that since the rubbed glass and resin before being separated exhibited no powers of attraction or repulsion on external bodies the amount of electrification produced on the glass exactly neutralizes the effect of, and therefore is equal and opposite to that produced on the resin.

It should here be noticed that an electrified body exerts no force on any non-electrified body, but that when it appears to do so as in the case in which rubbed glass or resin was seen to attract light bodies, the electrified rubbed substance first acts on the neutral bodies and electrically excites them by its influence or "inductively" (*see* § 15), so that the attraction shown is not an action between an electrified body and neutral matter, but between two electrified bodies.

11. **Hypotheses of Fluids.**—Various hypotheses have been put forward to account for this action, all of which more or less fail to do so; two of these may, however, be noticed, more especially as, if cautiously used, they supply a convenient means for clearly expressing electrical facts, though it must always be carefully remembered that in using these modes of expression we are making no assumptions as to the truth or the reverse of the hypothesis, but merely using a convenient analogy. The first is the "two fluid" theory of Symmer. It is assumed that all matter contains an inexhaustible supply of a so-called electric fluid which is capable of being split up by friction or otherwise, into equal quantities of two fluids of opposite properties, viz., the so-called vitreous (positive) and resinous (negative) elec-

tricities, and bodies that display the properties that we have said are signs of electrification, are said to be charged with a certain quantity of one or other of these fluids, a certain quantity of positive or negative electricity. This hypothesis gives us in many cases a convenient method of expressing the facts, provided always that it be used as such, and is not pushed to the point of considering that the electric fluids are any real entities or have any actual existence. It is obvious that it is an essential part of the hypothesis that both fluids shall always be produced in equal quantities.

In the "one fluid" theory which was favoured by Franklin, bodies that were positively electrified were looked upon as containing an excess of electric fluid, bodies that were negatively electrified were looked upon as suffering from a deficiency, while all bodies in the normal neutral state were looked upon as having neither an excess nor a deficiency. It is obvious that this hypothesis has the same advantages and defects as the other. In the sequel we shall use indiscriminately the language of either hypothesis whenever it is convenient to express any fact in terms of them.

A warning of Prof. Clerk Maxwell's may be quoted *àpropos* of this point. He says, "and here we may introduce once for all the common phrase, *the electric fluid*, for the purpose of warning our readers against it. It is one of those phrases which, having been at one time used to denote an observed fact, was immediately taken up by the public to connote a whole system of imaginary knowledge. As long as we do not know whether positive electricity, or negative, or both, should be called a substance or the absence of a substance, and as long as we do not know whether the velocity of an electric current is to be measured by hundreds of thou-

sands of miles in a second, or by an hundreth of an inch in an hour, or even whether the current flows from positive to negative, or n the reverse direction, we must avoid speaking of the electric fluid."

12. **Electrics and non-electrics.**—All bodies when rubbed with suitable precautions are, to use Gilbert's term, *electrics*, or rather we should say, that whenever any two bodies are rubbed together, electrical separation occurs, one body becoming positively and the other negatively electrified, although in many cases it is difficult to observe this owing to the escape of the charge by conduction or otherwise, and in fact it is possible to arrange all substances in a list, so that when any pair of them is rubbed together, the body higher in the list is positively electrified, while the other is of course negatively electrified to an equal extent.

Such a list is as follows:—Cat's fur, polished glass, flannel, leather, wood, paper, silk, shellac. Thus:—Glass rubbed with cat's fur will be negatively or resinously electrified, while the same glass rubbed with silk will be positively electrified.

Any instrument by which electrical separation is produced may be called an electrical machine. For simple experiments, a glass rod which is rubbed with a piece of silk on which has been smeared some electrical amalgam* is such a machine. Some more elaborate electrical machines will be fully described in a future chapter.

13. **Electroscopes.**—Before going any further it is necessary to consider some means by which we may tell when a body is electrified. Instruments for this purpose are called electroscopes, or sometimes more

* Electrical amalgam is made of tin, one part, zinc, two parts, and mercury, six parts. (Tyndall's *Lessons in Electricity*, p. 7).

loosely electrometers. The simplest form of electroscope is that known as the gold leaf electroscope, which is made of two strips of gold leaf hung together from a wire. When these are electrified they repel each other and so indicate the presence of electrification.

14. **Conduction.** — Let any body, for instance a metal sphere, be electrified, taking care that it is supported by silk strings or otherwise insulated. Let it be connected with another similarly supported non-electrified body by means of a wire for an instant. Now let the second body be examined with the electroscope; it will be found to be electrified in the same sense as the first body but to a less degree; the charge of the first body has been partly *conducted* along the wire connection and has been divided between the two bodies. If connection had been made with a glass rod, a stick of resin, or a silk thread, no transfer of charge would have occurred. The metal wire is therefore a conductor of electricity, the glass rod, &c., are not, they are insulators. This experiment explains why it was necessary to support the charged bodies we have been dealing with by silk threads, it also explains how it was that all the *electrics* known to the ancient electricians were insulators or non-conductors of electricity, since though conductors can be readily excited by rubbing with proper substances, special means must be taken to insulate them that the charge may not leak away before the electrification can be observed.

Substances vary very much in their power of conducting electricity, thus metals are good conductors, water and the body are fairly good ones, wood and cotton are poor conductors, while wool, silk, oils, resins and most kinds of glass are good insulators, and sulphur and dry air are among the best insulators known to us.

15. **Induction.**—"A conductor can be electrified either by a transfer of electricity between it and another conductor, or by an alteration in the distribution of the electricity on its surface, without any transfer of electricity between it and another conductor. In the former case the body is said to be electrified *by conduction*, in the latter *by induction* or *inductively*.

"Acting inductively on an uncharged conductor produces no charge on it as a whole, but merely induces equal and opposite charges on its two sides or ends.*

16. **Electric Quantity.**—Hitherto in this chapter the consideration of quantity of electricity has been left in the background, and electrification has been spoken of rather as a state or quality super-induced in bodies by certain processes. It is now necessary to arrive at a definite conception of this state as a measurable quantity, *i.e.*, as brought about by the presence of a real or hypothetical something which can be measured and which is called electricity, a something which has been referred to for convenience sake in the language of the "fluid" hypothesis as if it were an actual fluid, but which, it must be borne in mind, is not that, whatever else it may be. Let us suppose the existence of a something which is measurable and which when present in any body endows it with the properties just described under the name of electrification, and which is called Electricity. This electricity then is of two kinds, one named positive or vitreous, and one negative or resinous. It has been seen already that positive electricity repels positive, and that negative repels negative, while positive electricity attracts negative and *vice versâ*. This has to be expressed in terms of some unit, to be chosen once for all.

* Ayrton, *Practical Electricity*, p. 97.

*Unit of Quantity.**—That quantity of electricity, which when supposed collected at a point will repel an equal quantity of similar electricity collected at a point, and placed at unit distance from the first with unit force, shall be taken as the unit quantity of electricity.

Now in this definition the unit quantity of electricity is made to depend on the units of length and of force, and this latter is defined with reference to the units of length, mass and time. Hence the unit quantity of electricity has been completely defined in terms of the units of length, mass and time. For scientific purposes these are taken as one centimetre, one gramme and one second respectively.

There is one matter that has not explicitly been taken into consideration in thus defining the unit quantity of electricity, viz., the medium in which the action between the two charges takes place. It is assumed, however, that this is air, or more strictly speaking, a vacuum.

Now the attraction or repulsion between two quantities of electricity is proportional to each, *i.e.*, is proportional to the product of the two quantities. It is also inversely proportional to the square of the distance between them, always of course supposing that the two quantities are collected at two points.

17. **Electromotive force, potential.**†—"Whatever produces or tends to produce a transfer of electrification is called *electromotive force.* Thus when two electrified conductors are connected by a wire, and when electrification is transferred along the wire from one to the other, the tendency to this transfer, which existed before the introduction of the wire, and which when the wire

* Maxwell's *Electricity and Magnetism*, vol. i., p. 44.

† Quoted from Maxwell's *Elementary Treatise on Electricity*, p. 5.

is introduced, produces this transfer, is called the electromotive force from the one body to the other along the path marked out by the wire.

"To define completely the electromotive force from one point to another, it is necessary in general to specify a particular path from the one point to the other along which the electromotive force is to be reckoned. In many cases, *e.g.*, in electrolytic, thermo-electric and electro-magnetic phenomena, the electromotive force from one point to another may be different along different paths; if we restrict our attention, however, as we must do in this part of our subject, to the theory of the equilibrium of electricity at rest, we shall find that the electromotive force from one point to another is the same for all paths drawn in air from the one point to the other.

"The electromotive force from any point along a path drawn in air, to a certain point chosen as a point of reference, is called the *electric potential* at that point.

"Since electrical phenomena depend only on differences of potential, it is of no consequence what point of reference we assume for the zero of potential, provided that we do not change it during the same series of measurements.

"In mathematical treatises, the point of reference is taken at an infinite distance from the electrified system under consideration. The advantage of this is that the mathematical expression for the potential due to a small electrified body is thus reduced to its simplest form.

"In experimental work it is more convenient to assume as a point of reference some object in metallic connection with the earth, such as any part of the system of metal pipes conveying the gas or water of a town.

"It is often convenient to assume that the walls, floor and ceiling of the room in which the experiments are carried on have conducting power sufficient to reduce the whole outer surface of the room to the same potential. This potential may then be taken for zero. When an instrument is enclosed in a metallic case the potential of the case may be assumed to be zero.

"If the potentials at different points of an uniform conductor are different there will be an electric current from the places of high to the places of low potential. At present we are dealing with cases of electric equilibrium in which there are no currents. Hence in the cases with which we have now to do the potential at every point of the conductor must be the same. This potential is called the potential of the conductor."

18. **Physical Analogies.**—"The idea of electric potential may be illustrated by comparing it with pressure in the theory of fluids and temperature in the theory of heat. If two vessels containing fluids are put into communication by means of a pipe, fluid will flow from the vessel in which the pressure is greater into that in which it is less till the pressure is equalized. This, however, will not necessarily be the case if one vessel is higher than the other, for gravity has a tendency to make the fluid pass from the higher to the lower vessel. Similarly when two electrified bodies are put into electric communication by means of a wire, electrification will be transferred from the body of higher potential to the body of lower potential, unless there is an electromotive force tending to urge electricity from one of these bodies to the other, as in the case of zinc and copper. Again if two bodies at different temperatures are placed in thermal communication either by actual contact or by radiation, heat will be

transferred from the body at the higher temperature to the body at the lower temperature, till the temperature of the two bodies becomes equalized. The analogy between temperature and potential must not be assumed to extend to all parts of the phenomena of heat and electricity. Indeed this analogy breaks down altogether when it is applied to those cases in which heat is generated or destroyed. We must also remember that temperature corresponds to a real physical state, whereas potential is a mere mathematical quantity the value of which depends on the point of reference we may choose. To raise a body to a high temperature may melt or volatilize it, to raise a body, together with the vessel which surrounds it, to a high electrical potential produces no physical effect whatever on the body. Hence the only part of the phenomena of electricity and heat which we may regard as analogous is the condition of the transfer of heat or of electricity according as the temperature or the potential is higher in one body or in the other. With respect to the other analogy—that between potential and fluid pressure—we must remember that the only respect in which electricity resembles a fluid is that it is capable of flowing along conductors as a fluid flows in a pipe."

In terms of this analogy the electricity is compared to the fluid, while the pressure of the fluid at any point answers to the potential of the electricity at a corresponding point, the difference of pressure between two points causes the flow of fluid from one to the other; while similarly the electro-motive force or difference of potential between two points causes the flow of electricity from one to the other.

The conception of electric potential is a very difficult one, and this is not the proper place for a discussion of

it in all its bearings ; enough has been said in the long quotation from Clerk Maxwell to give some idea of the meaning of the word, but the student who wishes to obtain a thorough insight into it cannot do better than read Clerk Maxwell's *Elementary Treatise on Electricity*, giving special attention to Chapter III., on "Electrical Work and Energy." In most of what follows and especially in the part which refers to electricity in motion the idea of electric pressure in connection with the word potential will be the dominant one, but it must always be remembered that this idea of pressure is based on the analogy of the electric flow to a fluid flow, and this is at best very imperfect.

19. **Electrometers.**—The only thing that can be observed in connection with electricity at rest is a difference of potential. It is possible to measure the quantity of electricity driven through certain instruments, just in the way that a quantity of water driven through a water meter can be measured, and some of these instruments will be discussed in a future chapter ; but for the present we can only appreciate electrical charge by observing a difference of potential, and electroscopes and electrometers are instruments for showing or measuring differences of potential.

The gold leaf electroscope has been shortly described above. The divergence of the leaves of this instrument may be taken as an indication that the knob or disc, which was termed by Faraday the *electrode*, or way by which electricity enters the instrument, is at a different potential to the walls of the room, or to that of the metal cage that surrounds some forms of the instrument, but obviously without further observation it does not tell whether the potential is higher or lower, *i.e.*, more positive or more negative, and further tests must be made

to discover this. Neither does it give us more than the roughest indication of the amount of difference of potential. In cases where there is a great difference of potential, and a delicate gold leaf electroscope is likely to be spoilt, rougher forms may be used, *e.g.*, Dutch metal or even pith balls suspended by linen threads may be used instead of the more delicate gold leaf.

If it is required to measure a difference of potential an *electrometer* must be used. There are many forms of these, most of which are due to the inventive genius of Lord Kelvin. Descriptions of the various forms will be found in most text-books, such as for instance in S. P. Thompson's *Lessons in Electricity and Magnetism*, or the article "Electrometer" in the last edition of the *Encyclopædia Brittanica*, but best of all in Sir W. Thomson's papers on *Electro-statics and Magnetism*, pp. 263 *et seq.*

20. **Distribution of Charge; Density.**—It has been observed that the whole of an electric charge resides on the surface of a charged conductor, and this has been proved by direct experiment in many ways. It is found that while the distribution over a sphere is uniform, as might be expected from the symmetry of the figure, it is not so on conductors of other shapes. On these the charge per unit of surface, which is called the density, is greater the greater the curvature of the surface, till at a sharp edge or a point the density becomes so great that a discharge takes place. For this reason if a point is attached to a charged conductor a stream of charged particles of air is repelled from the point, giving rise to a wind setting from the point and rapidly discharging the conductor.

21. **Action of Points.**—This action of points becomes of great importance in electrical machines, and sometimes in electrical treatment. In the first place

the presence of a point on a charged conductor renders it impossible to keep a charge on the conductor, however well it may be insulated. But the same effect will occur if a point be presented to a charged conductor; for the charge, which we will suppose is positive, of the conductor acting inductively on the point will induce a negative charge at the point, the density of which will become so great that it will be discharged to the original conductor, neutralising its positive charge, and leaving the conductor which bears the point positively charged if it is insulated. It is by this means that the prime conductors of most electrical machines are charged from the excited plate or other moveable part.

22. **Capacity.**—The quantity of electricity that is required to raise the potential of any conductor from zero to unity, all other conductors in the neighbourhood being kept at zero potential, is called its *Capacity*.

As the charge resides only on the surface of a charged body the capacity of a conductor is determined by the extent of its surface, a body of large surface has a larger capacity than a body of smaller surface.

When a conductor is said to have a given capacity, it must not be thought that the conductor can hold only a certain fixed charge, in the way in which a bottle can be said to hold only so much water, because the quantity of electricity that can be put into a conductor of a certain capacity depends upon the potential or pressure at which it is charged. A body of unit capacity holds unit quantity when charged to unit potential, and holds ten times as much when charged to ten times the potential. On this account it is necessary to know both the capacity of a conductor, and the potential to which it has been charged, before forming any idea of the quantity of electricity which it contains. The

capacity of a conductor may be compared to the capacity of an elastic bag. The amount of air or of water that can be forced into an elastic bag depends upon the pressure at which it is forced in, and provided the bag does not burst, it can be made to hold more and more by increasing the pressure at which it is charged.

The capacity of a conductor is increased by bringing near to it other conducting bodies, which are maintained at zero potential by being connected to earth, and it may be stated generally that the nearer uninsulated conducting bodies are to a conductor the greater becomes the capacity of that conductor.

The importance of this point is well brought out by an example. The capacity of a sphere of ten centimetres radius suspended freely in space is ten units, but if another sphere of eleven centimetres radius be placed concentrically to it, so that the two spheres are separated from one another all round by one centimetre of air, and if the outer sphere be maintained at zero potential by connection to earth, then the capacity of the inner sphere is no longer ten, but 110 units, while if the radius of the outer sphere be reduced to ten and a half centimetres, the capacity of the inner one would become 210 units.*

23. **Condensers.**†—An apparatus consisting of two insulated conductors, each presenting a large surface to the other, with a small distance between them, is called a condenser, because when one conductor is connected to earth, a small electromotive force is able to charge the other with a much larger quantity of electricity

* If a be the inner and b the outer sphere, then the capacity of a is given by the formula $\frac{ab}{b-a}$.

† Maxwell's *Elementary Treatise on Electricity*, Chap. VIII.

than if it stood alone, *i.e.*, its capacity is increased by the proximity of the other conductor.

The simplest form of condenser consists of two metallic discs supported on insulating stems and facing each other, the intervening non-conductor or *dielectric* being air. If now a different dielectric, as for example, a sheet of glass, be inserted instead of air, the capacity of the condenser will be found to be different and greater than before, thus, the action across the dielectric depends on the nature of the dielectric.

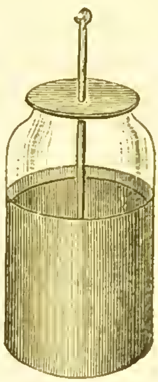

FIG. 1.—Leyden jar.

Since a glass condenser has a higher capacity than an air condenser, glass is said to transmit induction better than air, or in other words, glass has a higher *dielectric constant* or *specific inductive capacity* than air.

24. **Leyden jar.**—The electrical condenser most often used in experiments on static electricity is that known as the Leyden jar (fig. 1).

The ordinary form of this apparatus is a glass jar or bottle coated inside and out with metal foil to within two or three inches of the top. Through the cork of the bottle a wire passes, terminating above in a knob,

and below in a chain to make metallic contact with the inner coating. To charge the jar the outer coating is connected to earth, and so kept at zero potential, while the inner coating is connected with the conductor of an electrical machine or charged by an electrophorus. The charge given to the inner coating acts inductively upon the outer coating across the dielectric of the jar, which is thus able to retain its charge. It may be discharged by bringing a metallic conductor, which is in connection with the outer coating, near to the knob of the jar. A spark will occur and the jar is discharged.

The capacity of a Leyden jar depends upon the area of the surfaces coated with tinfoil, and also from what has been said in § 22, upon the thinness of the glass of which it is made. If the glass be very thin it may give way under the strain when charged to a high potential, and be broken to pieces.

25. **Contact electromotive force.**—It was observed at the end of the last century by Volta, that when dissimilar metals, such as zinc and copper, were brought into contact in air, electrical separation took place, and a difference of potential was set up between the metals, the zinc being positive to the copper, or at a higher potential. Under these circumstances this difference of potential does not efface itself by discharging across the junction of the two metals, as a difference of potential between two parts of a homogeneous conductor would do. If it could do so there would be a continual flow of current from zinc to copper, and this would result in the heating of the circuit, and an expenditure of energy or rather in a creation of energy, which is impossible. Again, the electromotive force set up at the junction of the two metals could only discharge itself across the junction by a flow in the opposite direction to that in

which it tends to cause a flow, but that is absurd. But if the two pieces of metal while in contact are immersed in some liquid that is capable of acting chemically on one of them, *e.g.*, dilute sulphuric acid, a complete circuit is formed, and the discharge can take place through the liquid, which undergoes decomposition thereby, and the difference of potential being continually renewed, a continuous discharge takes place round the circuit in the following way:—

Positive electricity passes across the junction of copper and zinc, and then from the zinc across the liquid to the copper again. If the connection of copper to zinc be by a wire, as is usually the case, we may use the language of the two fluid hypothesis and look on the junction as a sort of pump driving positive electricity round the circuit, so that it passes from zinc across the liquid or electrolyte to copper, and back to the zinc again along the metallic connection between it and the copper, thus making a true circuit.

This theory of a contact electromotive force is not altogether satisfactory, since it fails to explain many facts that are observed, moreover the seat of the supply of energy to the circuit is certainly not at the junction of the copper and zinc, where it should be to accord with the theory. It must therefore be looked on as merely a working hypothesis of the same class as the fluid theory of § 11, until a satisfactory theory is propounded.

26. **Voltaic cell.**—Such an arrangement is called a Voltaic cell, and but for disturbances that will be more fully considered in Chap. V., it would give a continuous current, till either the zinc or the exciting liquid (called the *electrolyte*) was exhausted. The difference of potential in a cell, or its *electromotive force*, is due to the contact

electromotive force of the metals forming the poles of the cell, though in certain cases this may be slightly modified by the liquid used. It is possible to increase the electromotive force by joining together a sufficient number of simple Voltaic cells, zinc of one to copper of the next. Such a combination of cells is called a battery, and the cells are said to be joined *in series;* and the electromotive force of the battery is equal to the sum of the electromotive forces of the cells which compose it.

It is customary in some textbooks to speak of the zinc

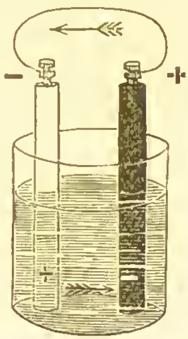

FIG. 2.—Single Voltaic cell showing poles and direction of flow inside and out of cell.

plate of a battery as the positive plate, and the copper or other plate as negative, while the terminal attached to the zinc plate is called the negative pole, and that attached to the copper the positive. The origin of this very confusing nomenclature is no doubt the fact that in the battery the positive direction of flow of the current is from zinc to copper, and that zinc is said to be electropositive to copper. But in the connecting wire the positive direction of flow of the current is from copper to zinc (see fig. 2), and as this is the portion of the circuit that we are most concerned with, the word

positive will be used to denote the positive pole of the battery and also the plate connected with it, when it is necessary to specify this. This is in conformity with the usage of electrical engineers, who speak of the peroxide plates in an accumulator as "positives."

27. **The Magnetic Needle.**—When a magnet is suspended freely at the surface of the earth it is found that it swings so as to set itself with one pole pointing towards the North (or at least approximately so) and the other towards the South. These poles are spoken of as the *North seeking* and *South seeking* poles respectively, and their names are abbreviated into N. and S. for convenience.

28. **Oersted's experiment.**—Let a small magnet, say a compass needle, be suspended freely at rest. It will point North and South, now over it let there be carried a wire joining the two terminals of a Voltaic cell or battery in such a way that its course from copper to zinc along the wire shall be from South to North, *i.e.*, so that the current (the positive direction of flow) is from South to North, then the North seeking end of the magnet will be deflected towards the West. This observation is due to Oersted of Copenhagen, and it was formulated by him into a law for telling the direction of flow in a circuit thus:—Imagine a man swimming with the current in the wire, *i.e.*, from copper to zinc and facing the needle, the North seeking end of the magnet will always be deflected towards his left hand, whatever the position of the wire with regard to the magnetic needle.

29. **Magnetic field. Lines of force.**—The region of space about any magnet and throughout which we consider its action is called its *field*, and lines of magnetic induction or lines of force round a magnet can be

mapped out. These will then all start from points or surfaces indued with N magnetism and end in points or surfaces indued with S magnetism and the intensity of a magnetic field at any point will be given by the number of lines of force which cross per unit of surface at right angles to them at that point.

It is easy to map the field of force round any magnet, since every magnet tends to set itself parallel to the lines of force at the point where it is. If then the magnet whose field is to be mapped be laid down on a sheet of white paper, and a small compas needle be moved

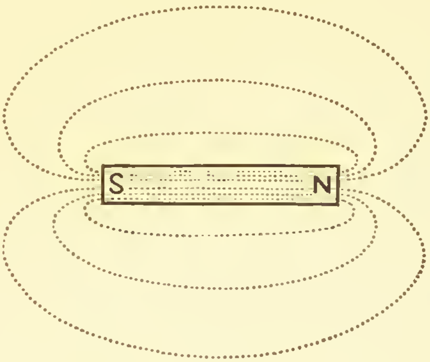

FIG. 3.—Lines of force of a bar magnet.

about in its vicinity, the direction of the needle at any point will give the direction of the lines of force at that point and these can be plotted on the paper. And soft iron filings, in a magnetic field, become magnets themselves by induction, and so set themselves along the lines of force, mapping them out to the eye in a very beautiful manner.

If a sheet of paper be laid down over a bar magnet, and iron filings be sifted over the paper, and the paper be gently tapped, they will arrange themselves into a figure composed of curved lines which emerge from one

pole, and pass round to converge at the other (see figure 3).

30. **Field of force about a wire carrying a current.**—To return to the electric current. We can now draw a deduction from Oersted's experiment (§ 28), viz., that there must be a magnetic field of force about every wire that is carrying a current, and since, when we are facing the magnet and swimming with the current, the N pole is always deflected to the left whatever the position of the magnet with regard to the wire, it follows that the lines of force must pass round the wire in circles, and it is easily shown that they do so by scattering iron filings on a card, through a hole in which a vertical wire carrying a moderately strong current is passed; when the card is tapped the filings instantly arrange themselves so as to map out the lines of force as circles round the wire; also if we look along the wire from copper to zinc, *i.e.*, with the current, the direction of the lines, the direction in which a N pole will move, is that of the hands of a clock. If a wire be bent into the arc of a circle, when a current passes through this arc there will be a field of force at the centre of the circle due to the current at all points of the arc. If the arc were in the plane of the paper and the current ran counter clock-wise in it, the direction of the lines of force would be vertically up from the paper.

31. **Galvanometers.**—Oersted's discovery enables us to make an instrument for measuring the current in any circuit. Such an instrument is called a *galvanometer*; or when, as is frequently the case, it is used merely to indicate the presence of a current it may be called a *galvanoscope*.

In its simplest form, stripped of all non-essentials, the

galvanometer consists of a coil of one or more turns of wire with a small magnet suspended freely at the centre. The coils may be, and generally are, circular, but frequently for convenience of construction or other reasons they are wound in other shapes. The needle being suspended freely sets itself parallel to the magnetic field that happens to exist at the place where the galvanometer is to be used, and the coils of the instrument are then set parallel to the needle and therefore to the magnetic field at the place. Hence the field due to a current circulating in the coils will be at right angles to the permanent field with which it is to be compared and will tend to deflect the needle.

In order to read the deflections of the needle when the galvanometer is in use, one of several devices may be applied. The simplest, where very accurate reading is not essential, is to attach to the needle a very light long pointer which passes over a scale. The pointer is sometimes attached at right angles to the magnet so that its movements can be observed without hindrance from the coils. The pointer may be made of straw or aluminium or paper.

By multiplying the number of turns of wire in the galvanometer coils the action of the current on the needle becomes increased in proportion, each turn exercising its own effect. On this account the name of "multiplier" was once given to the galvanometer. But it must not be forgotten that if the number of windings be largely increased, an obstacle to the passage of the current, or a resistance is thus introduced, which may have the effect of largely diminishing the current flowing through the coils. It is therefore necessary to wind galvanometer coils so as to suit the special purposes for which they are intended to be used. The galvanometers

used for medical purposes are generally wound with several hundreds or even thousands of turns. The resistance thus added to the circuit may be considerable, but as the resistance of the body is itself very high, the effect of the galvanometer resistance in diminishing the current is comparatively slight, and is negligeable as compared with the advantage gained by the multiplying effect of the turns of wire upon the needle. Thus the small currents used in medical treatment are enabled to produce large deflections of the galvanometer needle.

It must not be forgotten that the deflection of the needle of a galvanometer is not in any way a direct measure of the current circulating in it. Galvanometers are constructed to suit the purposes for which they are intended, and while some instruments will give considerable deflections with minute or even infinitesimal currents, others may require currents of comparatively huge magnitude to produce even a slight movement of the needle. On this account it is necessary, before comparing the deflections of one galvanometer with another, to be able to express their deflections in current, and for every instrument a number has to be found, called the "galvanometer constant." This may be done by the aid of standard galvanometers, or by the use of a voltameter (see Chap. IV.). In buying an instrument, however, it is customary to specify the magnitudes of current which it is proposed to measure with the galvanometer required; the instrument maker is then able to provide a suitable instrument, which has been already graduated to read directly into current.

There are certain features that from the nature of the work they are called upon to perform are common to most galvanometers for medical purposes. The most important is perhaps the method of graduation. These

galvanometers are invariably of the fixed coil or "tangent" form, that is to say, the current indicated by any reading is proportional not to the angle of deflection but to the trigonometrical tangent of that angle. Hence it is necessary that the circle on which the position of the needle of the galvanometer is read must be graduated, not uniformly, but so that the readings are angles whose tangents increase uniformly.

32. **Unit of electromotive force.**—A current is set up in a circuit by electromotive force (*see* def. § 17); that is to say the current in any part of a circuit is due to the difference of potential between the ends of that portion of the circuit. This can be measured by means of an electrometer. But the difference of potential between any two points A and B is measured by the work done in bringing up unit quantity of electricity from B to A against the electrical forces of the system under consideration, hence the work given out when unit quantity of electricity runs down from A to B under the electrical forces of the system is equal to the difference of potential between A and B.

33. **Resistance.**—It is soon found in working with currents that with different amounts of wire in the circuit, different currents are produced by the same electromotive force. There is another factor that determines the strength of current besides the electromotive force, and this factor is called the *resistance* of the circuit. (*N.B.* Simple circuits and steady currents only are here considered, with variable currents it will be found that there are yet other factors that affect the matter).

34. **Ohm's law.**—The law showing the relation between electromotive force, resistance and current was enunciated by Dr. G. S. Ohm and is known as Ohm's law. It is as follows:—*The strength of the current in any*

circuit or part of a circuit varies directly as the electromotive force in that circuit and inversely as the resistance of the circuit. This may be expressed in symbols thus :—

$$C = \frac{E}{R}.$$

Where C stands for the current, E for the electromotive force, and R for the resistance. From this formula we obtain in addition $E = CR$, or $R = \frac{E}{C}$. Thus we can calculate either C, E or R, if the values of the other two symbols are known.

35. **Practical units.**—The electro-magnetic units, as in the case of the electrostatic units, are all ultimately defined in terms of the units of mass, length, and time, and as in all electrical and other scientific calculations these are taken to be one gramme, one centimetre and one second respectively, the system of units is known as the absolute or centimetre-gramme-second (C.G.S.) system. It is found, however, that for practical calculation and use these units are not of a convenient size, *e.g.*, the units of electromotive force and of resistance are inconveniently small, and that of current is inconveniently large. The following system of units derived from these has therefore been adopted for practical use.

Electromotive force.—The practical unit is called the *Volt.* It is a little less than the electromotive force of one Daniell's cell.

Resistance.—The practical unit of resistance is called an *Ohm.* The Paris Congress of Electricians in 1884 defined an unit of resistance to be called a "*legal Ohm.*" It is represented by the resistance of a column of pure mercury at 0° C., one square millimetre in section, and

106 centimetres long, it is less than the true ohm* by about ·3 per cent.

Current.—The current which is given by an electromotive force of one volt acting through a resistance of one ohm is called one *Ampère.*

Quantity.—One ampère flowing for one second carries one *Coulomb* of electricity, past any point in the circuit. Another unit of quantity much used by engineers is the quantity of electricity which would be carried by one ampère in an hour. This is called an *ampère-hour.* It is equal to 3600 coulombs.

Capacity (see § 22).—That capacity which would require one coulomb to charge it to one volt, is called one *Farad.*†

Even these units are inconveniently great or small at times, so certain prefixes are used to the names to denote multiples or sub-multiples of these quantities. Thus, a *megohm* is one million ohms, a *micro-volt* is one-millionth of a volt, a *microfarad* one millionth of a farad, a *milliampère* is one thousandth of an ampère; this last is the unit of current used in medicine.

36. **Specific resistance.**—The electrical resistance of any material is a property peculiar to that material just as its hardness or colour or density is. Most metals are good conductors, but they vary greatly among themselves in their electrical conductivity. Silver is the best conductor of electricity and copper comes near to it. Platinum has about six times the resistance of silver, and iron has a resistance slightly greater than that of platinum. As a general rule alloys have a higher resistance than the pure metals; German silver having

* One thousand million C.G.S. units.

† These names commemorate the labours of Volta, of G. S. Ohm, of André Ampère, and of Michael Faraday.

about fourteen times the resistance of silver. Tables showing the relative conductivity of metals and other bodies are given in text-books such as S. P. Thompson's *Lessons*.

Tables of resistance are also made with the *specific resistances* of the materials tabulated. Such tables will be found in Everett's *Units and Physical Constants* or in S. Lupton's *Numerical Tables*.

The specific resistance of a material is defined as the resistance of one cubic centimetre of the substance considered.

If the specific resistance of a substance is known, the resistance of any wire or rod of that substance can be calculated.

The resistance is directly proportional to the length of the conductor, and inversely so to its cross-section.

In general the resistance of metals increases with temperature. That of carbon, however, decreases considerably, and in this respect behaves in the same way as electrolytic conductors do (*see below*). The carbon filament of an incandescent lamp has nearly twice the resistance cold that it possesses when hot.

37. **Measurement of resistance.**—Ohm's law may be applied to measure the resistance of any given conductor, or rather to compare the resistances of two conductors.

Suppose that the current, passing through a galvanometer can be read off from the deflection of the needle, and it is required to find the value of the resistance R. Join up the resistance R with the galvanometer and battery as in the figure, then since by Ohm's law

$$R = \frac{E}{C}$$

if E the electromotive force of the battery is known, and C, the value of the current, is read off from the galvanometer then the total resistance of the circuit, can be easily calculated. But this is made up of R the resistance to be measured, and r the resistance of the battery, and g that of the galvanometer. *E.g.* Suppose a Daniell's battery of electromotive force 1·08 volts and resistance ·58 ohms, and a galvanometer whose resistance is 66·3 ohms are used, and the reading of the galvanometer is ·006 ampère (six milliampères) we get

$$R + r + g = \frac{1{\cdot}08}{{\cdot}006} = 180 \text{ Ohms},$$

$$or\ R = 180 - 66{\cdot}88 = 113{\cdot}12 \text{ Ohms}.$$

When exact measurements are required, however, we should not rely on knowing the electromotive force or

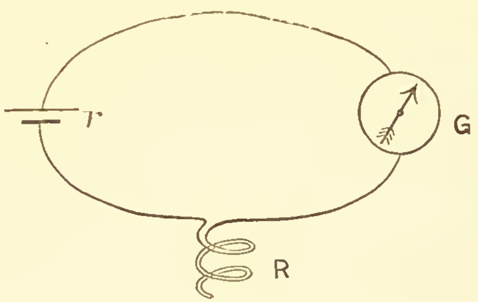

Fig. 4.—Typical circuit.

resistance of the battery with sufficient accuracy for this, so the method must be so modified as to eliminate these. Methods of doing this are described in *Practical Physics* by Glazebrook and Shaw, in the *Textbooks of Science* series, or in *Practical Physics*, vol. ii., by Balfour Stewart and Gee. The method, however, is quite good enough to be useful in certain cases.

By obvious modifications this method may be used for the determination and comparison of the resistances

of batteries or galvanometers, or for the determination of the electromotive force of a battery.

38. **Current sheets—Current density.**—When a current is led into a large conductor the lines of flow spread out through the conductor. They all of course pass from the anode to the kathode, but spread out into sheets in doing so. The current which passes across unit of sectional area, taken at right angles to the lines of flow at any point, may be called the *density* of the current at that point. In the case of a current in a wire conductor we consider the whole current since the whole sectional area of the wire is taken into account, but with currents flowing in large and heterogeneous conductors like the human body, or even in electrolytes where the density of the current may vary from point to point, it is necessary in order to estimate the effect at any point, to take into consideration the density at that point rather than the whole current. For the physiological effects are largely dependent on the density, that is the ratio of current to sectional area, just as in a wire, the heating effect is, other things being equal, proportional to the square of this ratio. For example, in a wire of a variable diameter the heating effect will be far greater in the thinner parts of the wire, where the density of the current may be said to be greater, though the actual current in all parts is the same. In a conductor such as the human body, some of the lines of flow of the current will leave any muscle or nerve quite near the electrode by which they enter, and will pass to the other electrode through the other tissues. This gives rise at times to a series of virtual electrodes along the course of a nerve which may be of some importance. (*See* Chap. V.).

39. **Electrolysis.**—In § 26 it was pointed out that

during the passage of an electric current through a battery the liquid, or as we then called it the electrolyte, was decomposed, and this decomposition is essential to the passage of the current. Examining into the decomposition more closely, it may be looked on as if it took place as follows :—Owing to the difference of potential set up between the plates, say of zinc and copper, the zinc plate being positive attracts to itself the electronegative portion or *ion* of the electrolyte. In the case of sulphuric acid (H_2SO_4) this is the group of atoms SO_4. At the same time the copper plate being at the lower potential, and therefore negatively charged with regard to the zinc, attracts the electropositive *ion*, *i.e.*, the hydrogen, and the state of affairs may be thus represented,

$$\begin{array}{cccccccccc} Zn & SO_4 & H_2 & SO_4 & H_2 & SO_4 & H_2 & SO_4 & H_2 & Cu \\ + & - & + & - & + & - & + & - & + & - \end{array}$$

i.e., a chain of molecules polarized under the influence of the contact difference of potential between copper and zinc. But the *ion* SO_4 is capable of combining with the zinc and so neutralising its positive charge, and the *ion* H_2 is set free on the copper, thus neutralising the corresponding negative charge there. Immediately of course the same action recurs owing to the continuously acting contact electromotive force between copper and zinc. In this way a continuous current is kept up, and a continual double procession of the molecules of the electrolyte or ions occurs in the liquid part of the circuit, the electropositive ion passing always towards the copper or positive pole of the battery and the electronegative ion towards the zinc, so that we may regard the copper plate as receiving positive electricity continually from the electrolyte, and passing it on to the circuit. The hydrogen given off at the copper plate

does not escape instantaneously, and unless means are taken for removing it, it will set up a back or reverse electromotive force which will greatly reduce the efficient electromotive force of the battery. The battery is then said to be *polarized*. Many methods, chemical and mechanical, have been suggested for overcoming this difficulty, some of which will be described in Chapter III.

If the wires leading from the terminals of a battery are not joined but are led into another electrolyte, an action corresponding to that which takes place in the battery will occur. There will be a tendency to decompose the electrolyte, and if there is sufficient electromotive force in the circuit to overcome the reverse electromotive force of the electrolyte, electro-decomposition or *electrolysis* will take place. Taking the case of water (in practice the water is slightly acidified with sulphuric acid to increase its conductivity) the changes are as follows :—

40. **Anode and kathode.**—Suppose that the poles of the battery are connected to two platinum plates in the water. These plates are called the electrodes. That connected with the copper pole is the one by which the current (considered as a flow of positive electricity) enters the electrolyte and is called the *Anode*, that connected with the zinc is called the *Kathode*, *i.e.*, the pole by which the current leaves the solution. In the beginning the anode is positive, the kathode negative. The ions in the case of water are hydrogen and oxygen and the former is electropositive and therefore appears at the kathode or negative pol and is called the *kation*, while the oxygen appears at the anode and is called the *anion*. The arrangement of the molecules may be represented thus :—

$$\begin{array}{ccccccccc} \text{Kathode} & H_2 & O & H_2 & O & H_2 & O & \text{Anode.} \\ - & + & - & + & - & + & - & + \end{array}$$

If the electromotive force of the battery is not sufficient to overcome the back electromotive force due to the chemical affinity of the oxygen and hydrogen for each other, matters will rest like this, the electrolytic cell is *polarized*,* the current is stopped, and no appreciable decomposition or electrolysis will take place, but if the electromotive force is sufficient, *i.e.*, about 2 volts or more, decomposition will proceed, hydrogen being given off at the kathode, and oxygen at the anode.

41. **Laws of electrolysis.**—The laws of electrolysis were discovered by Faraday ; † they are as follows :—

a. The amount of chemical action is equal at all parts of a circuit. E.g. If several electrolytic cells, or *voltameters* ‡ as they are often called, be arranged in a circuit, the amount of decomposition will be the same in each. If they are water voltameters the same amount of hydrogen will be given off in each, if the electrolyte is copper sulphate solution the same amount of copper will be deposited in each. The same applies in the case of the anions. If some of the voltameters contain water and others contain sulphate of copper solution, the quantities of hydrogen and copper respectively will be proportional to their chemical equivalents.

b. The amount of any ion liberated in any given time is proportional to the strength of the current, and to the chemical equivalent of the ion.

The chemical equivalent for hydrogen is unity, there-

* It is easy to show that there is an actual reverse electromotive force in the electrolytic cell, by suddenly cutting out the battery and completing the circuit in which the electrolytic cell is included through a galvanometer, which will then indicate a small current in the opposite direction.

† *Experimental Researches*, Series V. and VII.

‡ For an account of Voltameters, see Chap. IV.

fore the weight of hydrogen liberated by one ampère running for one second, *i.e.*, by one coulomb of electricity, is the electro-chemical equivalent of hydrogen. For any other ion the product of the weight liberated by one coulomb, multiplied by the chemical equivalent of the ion, is called the electro-chemical equivalent of that ion. The electro-chemical equivalent of silver is very nearly ·001118 grammes per coulomb, and the quantity of silver which one ampère would deposit in an hour is 4·0246 grammes.

42. **Resistance of an electrolyte.**—Just in the same way as the resistance of a metal or other solid conductor is considered, we may speak of the resistance of a liquid or electrolyte. There is more difficulty in measuring this in practice in consequence of the reverse electromotive force of polarization, but if alternate currents be used the specific resistance of an electrolyte may be found, uncomplicated by polarization effects. The fact that electrolysis is taking place in an electrolyte does not prevent the consideration of its resistance in the same way as that of a non-electrolyte. The specific resistance of water is high, and the purer the water the higher it becomes; it would appear, according to the latest experiments that absolutely pure water if it could be obtained would be a perfect non-conductor.

43. **Heating effects.**—It was pointed out in § 39 that there is a relation between the electromotive force and the current in a circuit, and the work done in the circuit.

The rate of doing work may be expressed by the figure obtained by multiplying the current in the circuit by the electromotive force acting upon the circuit. So that the rate of doing work $W = EC$.

If E be measured in volts, and C in ampères, W is expressed in an unit known as a Watt.

A Watt is not a measure of work done, but of the rate of doing work. To obtain a measure of work done the time during which it goes on must be also considered. Thus one watt for one hour is a measure of work done.

By Ohm's law $E = RC$, and if in the above equation RC be substituted for E, we obtain the formula $W = C^2R$, for the rate of doing work.

In any simple conductor the energy expended takes the form of heat. We are consequently able to calculate the rate at which heat is generated in the conductor; and if we know its specific heat and the rate at which it loses heat at its surface, we can calculate the temperature after the current has passed for any given time.

44. **Electro-magnetic induction.**—Let us consider a coil of wire the ends of which are connected through a galvanometer. If a magnet be made to approach such a coil, the galvanometer will indicate a current, "the induced current," so long as the magnet is approaching. As soon as the magnet stops approaching, the current also ceases. If now the magnet be removed the galvanometer will indicate a current in the opposite direction. If the coil is made to approach and recede from a magnetic pole the same effects will be produced. In § 29 it was shown how a magnetic field might be mapped out by means of iron filings. A little consideration of the last experiment, and of fig. 3, will show that the approach of the magnet to a coil means the increase of the number of magnetic lines of force which pass through the coil, and that when the magnet is moved away the number of lines of force through the coil, or in other words the strength of field in the interior of the coil, diminishes. This effect of a varying magnetic field on a coil of wire placed in it is known as *electro-magnetic*

induction. It was discovered and investigated by Faraday, and the account of his experiments is contained in his *Experimental Researches*, Series I, II and III.

It is clear that since the induced current depends on the variation of the magnetic field in which the coil is placed, and on this alone, it matters nothing whether the field is caused to vary by moving a magnet or by making and unmaking a magnet by any means or by varying a current in another neighbouring circuit. In this latter case when the current in the inducing or primary circuit is made the induced current in the secondary is in the opposite direction, but when it is broken the induced current is in the same direction.

45. **Induced electromotive force.**—In order to arrive at the magnitude of the induced current we must consider that by Ohm's law this depends on two quantities, the electromotive force in the circuit and the resistance of the wire. This latter is constant since it depends only on the wire. The electromotive force alone varies. Its direction we have already considered, its magnitude is determined by the following law:—The total induced electromotive force in any closed circuit is proportional to the *rate of change* of the number of magnetic lines of force through the space enclosed by the circuit.

Since the magnetic permeability of soft iron is very great, compared with that of air, an obvious method of increasing the number of lines of force passing through the coil is to place a soft iron core inside it. Such an arrangement of a coil or helix of wire enclosing an iron core has strong magnetic properties and is known as an electro-magnet. If we are concerned with the induction between two circuits, the number of lines of force, or in other words, the strength of the

magnetic field produced by a current in a circuit is proportional to the current in that circuit. Hence in this case the law may run "*the induced electromotive force in any closed secondary circuit is proportional to the rate of change of current in the primary circui .*"

46. **Self-induction.**—Since a current passing in a coil of wire sets up a magnetic field of force in the interior of that coil, we should expect to find indications of the inducing action of this field of force on the circuit itself. In fact we do see such indications in the appearance of a spark whenever a circuit containing an electro-magnet or a large helix is broken. This action of an increasing or decreasing current on its own circuit is frequently spoken of as the *extra current*, but more correctly as an action of *self-induction.*

There is no essential difference between the action of a variable current on its own circuit and on another.

The self-induction current in a wire has often been compared to the inertia of a fly-wheel or of a current of water in a pipe such as is utilised in the case of the hydraulic ram, and the analogy is a very useful one and gives a very clear notion of its effects.

CHAPTER III.

Batteries and Apparatus.

Essentials of a good battery. Electromotive force of cells. Capacity of cells. Polarization. Depolarizers. Smee's battery. Bichromate battery. Daniell's battery. Grove's and Bunsen's batteries. Leclanché battery. Dry batteries. Chloride of silver battery. Oxide of copper battery. Sulphate of mercury battery. Latimer Clark's standard cell. Stöhrer's battery. Accumulators. Table of batteries. Choice of a battery. Care of a battery. The Induction Coil. Use of electric lighting currents.

47. **Essentials of a good battery.**—Numerous modifications of Volta's original cell have been from time to time proposed with the object of improving it in one way or another. There are three objects to be aimed at in designing a battery :—firstly, to obtain as high an electromotive force as possible; secondly, to diminish the internal resistance; and thirdly, to secure constancy of action, that is to say, the cell should be capable of giving the required current for a reasonable period without any serious fall of electromotive force from polarization (§ 51). For medical work perhaps the most important point of all is to find a cell which will remain for a long time in good order without attention, and in which no wasteful chemical action goes on when the battery is not in use. On this account the Leclanché battery (§ 57) or some modification of it has been almost universally adopted as the cell *par excellence* for medical purposes.

48. **Electromotive force of cells.**—The limit of electromotive force that can be obtained from a single cell is soon reached, since, as shown in § 39, it depends almost entirely on the contact electromotive force between dissimilar substances (metals or metalloids). We must note here that in a cell where the poles are say of zinc and platinum, the contact electromotive force is really that between zinc and platinum, although the zinc and platinum do not touch each other throughout the circuit. We may, however, look on it as made up of the contact electromotive force between the zinc plate and the copper connecting wire, plus that between the copper connecting wire and the platinum plate. Full tables are found in electrical text-books of metals arranged in order, the most electropositive at the head of the table, the most electronegative at the foot. An abbreviation of such a table* is the following :—

Electropositive.
Sodium.
Magnesium.
Zinc.
Iron.
Lead.
Copper.
Silver.
Mercury.
Platinum.
Carbon.
Electronegative.

This order is given for the elements in contact in presence of dilute acid ; under other circumstances the order is liable to alteration, and this fact is a serious difficulty in the way of the "contact" theory of electro-

* Miller's *Chemistry.*

motive force which has been taken as a working hypothesis for our purposes. We may refer the reader again to Dr. O. Lodge's *Modern Views.*, Chap. VI.

It follows that the battery with the greatest electromotive force would be one, the poles of which consisted of the two materials at the extreme ends of the table, and most of the improvements in batteries made with the object of increasing the electromotive force have been by substituting metals further down the table for the copper poles of Volta's cell. Thus in Smee's cell we find a platinized silver plate is used for the positive pole, in Grove's battery a platinum plate, while in Bunsen's carbon is used. Until therefore it becomes practicable to use magnesium or sodium instead of zinc, we can hardly expect to obtain primary batteries of higher electromotive force than those in which zinc and carbon poles are used. These batteries when working to the best advantage have an electromotive force of something under two volts. That of a Bunsen's cell is from 1·8 to 1·9 volts.

As will be seen in the description of secondary batteries a positive plate of peroxide of lead affords a means of getting a high electromotive force, and the combination of it with a zinc negative plate has been introduced under the name of the zinc-Lithanode battery, and it is said to have an electromotive force of 2·5 volts.

If several cells be coupled together in series, that is to say, with the negative pole of the first joined to the positive pole of the second, and so on, the electromotive force of the combination measured from the positive pole of the first to the negative of the last cell will be equal to the sum of the electromotive forces of the cells taken separately, thus, when high electromotive forces are required, the arrangement of a sufficient number of

cells in series provides a means of obtaining it. If ten cells of an electromotive force of 1·5 volts. apiece be arranged in series the electromotive force of the whole battery will be fifteen volts. In medical treatment an electromotive force of 30 or 40 volts. is commonly required; and a medical battery is therefore provided with a suitable number of cells connected together in series to give such a voltage.

49. **Internal Resistance.**—This is determined by the nature of the fluid in the cell, by the distance between the plates, and by the area of the plates. The internal resistance is low if the plates be large and close together, and high if the plates be far apart or small. If the whole circuit of a cell be considered, and divided into two parts, the external circuit in the wire, and the internal inside the cell itself, then a comparison of the resistances of the two parts will show what proportion of the total electrical energy of the battery is available for use in the external circuit, and what proportion is expended uselessly inside the cell itself, for example, in the case of a cell having an electromotive force of 1·5 volts, with an internal resistance of three ohms, and connected through an external resistance of six ohms, the energy expended in the outside circuit will be two-thirds, and that expended inside the cell will be one-third of the total. Of the total difference of potential, one-third (or ·5 volt) will be used up in the cell, and the remaining two-thirds (or 1 volt) will represent the available electromotive force of the cell for doing work in the outside circuit.

If the external resistance be 997 ohms and the electromotive force and internal resistance be as before, then the available electromotive force acting upon the external circuit will be very nearly the same as the

full voltage of the cell; actually it will be ·997 of 1·5 volts.

Thus one sees that in certain cases the internal resistance of a cell is an important factor in determining its value as a source of current, while in other cases it is insignificant. In working with the large resistances of the human body the internal resistance of the cells composing the battery is an unimportant matter, as it forms a small fraction of the total circuit, and the drop of electromotive force in the cells is therefore a small fraction also.

In working with low external resistances, as in cautery work, and to a less degree in the illumination of parts of the body by incandescent lamps, the internal resistance of the cells becomes important, and special forms of cell with very low resistances are designed for such work.

50. **Arrangement of Cells.**—The arrangement of cells in series has already been alluded to; and is repre-

FIG. 5.—Six cells arranged in series.

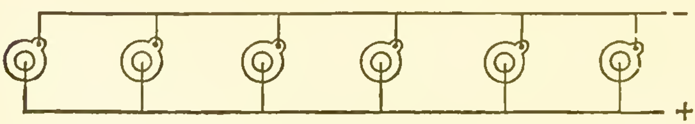

FIG. 6.—Six cells arranged in parallel.

sented in figure 5. Cells may also be arranged in parallel (fig. 6), that is to say two or more cells may have their positive poles connected together to form one pole of the battery, and their negative poles in like manner to form the negative pole. When cells are con-

nected in series the electromotive force of the battery is the sum of the electromotive forces of the cells composing it; the internal resistance of the battery is also the sum of the internal resistances of the cells. When similar cells are connected in parallel the electromotive force of the combination is no more than the electromotive force of one of its components; but its internal resistance is diminished in proportion to the number of cells coupled together. With six cells in parallel the internal resistance is one-sixth of that of one cell. It is sometimes useful to couple up the cells which are at hand in the best manner for obtaining the desired result as the following example will show:—

Suppose the resistance of a cautery is ·1 ohm and the cells to hand are ten bichromate cells of 1·6 volts each and ·5 ohm internal resistance, and suppose that the cautery requires eight ampères to heat it. If the cells are coupled up in series we shall indeed get an electromotive force of sixteen volts acting through a resistance of 5·1 ohms, and this will give a current of 3 ampères, but if they are coupled in parallel, the battery resistance will be only ·05 ohm, and the total resistance will be but ·15 ohm in the whole circuit. True the electromotive force will be only 1·6 volts, but by Ohm's law the current in this case will be 10·6 ampères. In the former case the cautery would not be heated, in the latter we should have enough current and to spare. *Vice versâ*, it is futile to arrange batteries in parallel when a current has to be passed through a high resistance, such as the human body, a resistance of at least 1000 ohms, compared with which the internal resistance of thirty Leclanché cells in series is small.

Taking the electromotive force and internal resistance of the cells as before, it will be useful to give illustra-

tions of the results of coupling up six cells in different ways. If in series (fig. 5) the electromotive force is 9·6 volts, and the internal resistance is 6 ohms, hence the maximum current that could be obtained would not much exceed 1·5 ampères. In a series of three, each of two set in parallel (fig. 7), the total internal resistance

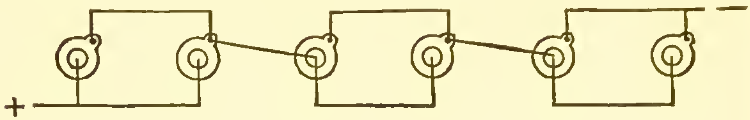

FIG. 7.—Six cells arranged in a series of three pairs.

will be 1·5 ohms, and the electromotive force 4·8 volts, and it would be possible to take a current of over three ampères from it. In a series of two sets of three each in parallel (fig. 8) we should get an internal resistance

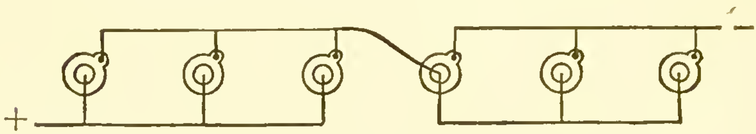

FIG. 8.—Six cells arranged in a series of two triples.

of ·66 ohms, and an electromotive force of 3·2 volts, which could give over 4·5 ampères. Finally, with all in parallel (fig. 6) there is an internal resistance of ·166 ohms and an electromotive force of 1·6 volts, so giving a maximum current of nearly ten ampères. The above calculations all suppose the battery to be short circuited, and therefore doing no external useful work; they also leave out all consideration of polarization.

51. **Polarization.**—Much attention and ingenuity have been concentrated upon securing constancy of current and absence of polarization in batteries. This is easily seen to be an important matter, for nearly all batteries undergo a rapid fall of electromotive force

when any large current is taken from them. Thus, for example, a form of cell recently put upon the market had an electromotive force of 1·508 volts on open circuit, but after being short circuited through a wire of low resistance for fifteen minutes the electromotive force had fallen to ·433 volts. Polarization of a cell is mostly caused by alterations in the surfaces of the plates of the cell, and chiefly by the condensation of hydrogen on the inactive plate which sets up a reverse electromotive force, and so reduces the available electromotive force of the cell, at the same time reducing the available area of the plates, and thereby increasing the internal resistance of the cell (see § 49).

There are other causes which tend to produce a falling off in the current that a cell can give, particularly the exhaustion of the exciting fluid, if it be not renewed from time to time.

To prevent polarization it is necessary to take some measures that will check or disperse the accumulation of hydrogen on the positive pole.

52. **Depolarizers.**—The constancy of batteries depends largely on the efficacy of the depolariser used. Depolarizing methods can be conveniently grouped under three heads. (*a*) Mechanical methods. (*b*) Liquid depolarizers. (*c*) Solid depolarizers.

In Smee's battery the surface of the silver plate is roughened by being platinized, *i.e.*, covered with finely divided platinum, the effect of which is that the bubbles of hydrogen are able to form and escape more easily. In Walker's modification of this battery, (see § 62, Stöhrer's battery) the rough surface of the carbon plate used plays the same part, but it probably acts chemically also by causing oxidation of the hydrogen in the same way that the carbon of charcoal filters causes the

oxidation of the organic matter of impure water. Another mechanical method of hindering polarization is to keep the exciting fluid well stirred by forcing air through it or otherwise. None of these methods, however, are so efficacious as the use of chemical means, that is to say the use of some oxidising agent in the cell whereby the hydrogen is consumed, instead of being deposited on the positive plate. The simplest method of doing this is to add to the exciting liquid some powerful agent that will oxidise the hydrogen as fast as it is liberated. This is the plan followed in the

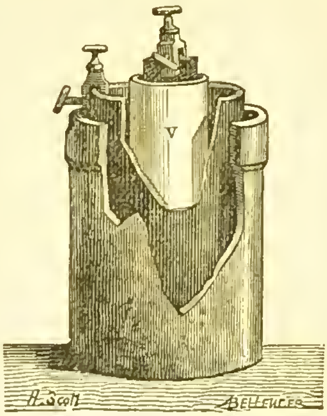

FIG. 9.—Two fluid cell.

"bichromate" battery (§ 54) invented by Poggendorf. Another liquid depolarizer that is much used is strong nitric acid, but as this attacks zinc violently it is necessary to separate it from the zinc plate by the use of a semi-permeable porous partition or porous pot, and the battery then becomes a two fluid battery. In fig. 9 the arrangement of a two fluid battery is shown; V is the porous pot containing one liquid and one plate, the other liquid and the other plate standing outside it.

There are several valuable solid depolarizers in use, the one best known being peroxide of manganese, which is used in the Leclanché cell, and in several of the "dry" cells. Oxide of copper is also used. Fused chloride of silver is the depolarizer in a battery known as the chloride of silver cell, and the valuable depolarizing qualities of peroxide of lead have had much attention drawn to them of late, through the study of its action in storage cells.

53. **Smee's battery.**—This battery is of interest, as representing the simplest advance on the copper zinc couple of Volta; it was invented in 1840. In its usual form it is made of two flat plates of zinc, separated from one another above by a block of wood which supports a platinised silver plate between the zincs. To the zinc plates there is attached a large clamp and binding screw, which serves to hold the element together, another binding screw is attached to the silver plate, and this is the positive pole of the battery. The exciting liquid is dilute sulphuric acid 1 to 10. In spite of the roughened surface of the silver plate the battery soon polarizes, and its available electromotive force is not much more than ·5 volt.

54. **Bichromate battery.**—This is a favourite form of cell where large currents are required occasionally. Its constancy, however, is by no means perfect. Its plates are of zinc and carbon, and the exciting liquid consists of a solution of potassium bichromate and sulphuric acid. The sulphuric acid in the first instance sets free chromic acid, leaving potassium sulphate in solution. The chromic acid being a very powerful oxidising agent, combines with the hydrogen liberated on the carbon plate by the action of the battery, and is reduced to chromous oxide; this combines with a

further quantity of sulphuric acid to form chromous sulphate, which remains in solution, giving the liquid a dark green colour. If such a battery is allowed to stand after much use, crystals of chrome alum (potassium chromium sulphate) will be deposited, which are very hard and difficult to dissolve. Sodium bichromate has been strongly recommended instead of the potassium salt, as the sodium chrome alum is very much more soluble; the sodium salt also contains, weight for weight, more chromic acid than the potassium salt. A suitable formula, if sodium bichromate be used, is the following :—Dissolve 200 grammes of the salt in 1 litre of water and add 150 c.c. of strong sulphuric acid,* when the battery begins to show signs of being exhausted an additional 25 to 50 c.c. of acid per litre may be added.

The zincs of this battery must always be removed from solution immediately after use, and in fact should be well washed and frequently re-amalgamated, if the battery is to give the best effect. The reason for this will be easily seen when it is pointed out that Dr. Weeren has lately observed that pure zinc is one hundred and seventy-five times more soluble in acid containing a little chromic acid than in pure dilute acid. Bichromate cells are frequently fitted up in portable induction coil sets. Forms of bichromate battery are well known to medical men under the name of Stöhrer's and Reiniger's batteries, but they are hardly to be recommended as they require much attention and cleaning. Stöhrer's battery will be more fully described in § 62. The outward form of the bichromate battery varies very much. A very familiar shape is that of a

* Sodium bichromate, 6¼ ounces; water, 35 ounces; sulphuric acid, 6 ounces.

wide mouthed and long necked bottle (fig. 10). The plates are suspended from a vulcanite lid carrying binding screws, and the zinc plate can be drawn up out of the liquid into the neck of the bottle when the battery is not in use.

55. **Daniell's battery.**—The oldest and most constant form of two fluid battery is that known as Daniell's cell. So constant is this cell that it has been proposed and frequently used as a standard of electro-

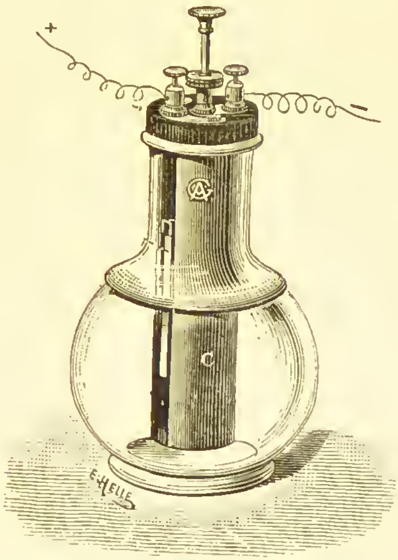

FIG. 10.—Bichromate battery.

motive force. For rough purposes we may take the electromotive force of a Daniell's cell at one volt. A Daniell's cell consists of a copper plate placed in a solution of sulphate of copper, which is kept saturated by leaving a few crystals of copper sulphate on a shelf near the top of the liquid; separated by a porous partition is a zinc plate in solution of sulphate of zinc

slightly acidified with sulphuric acid. Frequently the copper plate is made also to serve as the containing vessel. The porous partition while it prevents the mixing of the two solutions, offers but little resistance to the electrolytic passage of the current. The reactions then are as follows :—Zinc is dissolved at the zinc plate and hydrogen would be set free at the division between the two liquids but for the presence of the copper sulphate solution which being itself an electrolyte is decomposed into sulphuric acid, which passes inwards from the porous partition, and copper which is deposited at the positive pole. Since this latter is already of copper there is no tendency to polarization here at all, and any falling off in the electromotive force of the cell is due to bad amalgamation or some other fault at the zinc plate. Daniell's batteries are sometimes arranged as "gravitation batteries," the porous division being abolished and the lighter liquid dilute acid with the zinc plate being above the heavier sulphate of copper solution. Daniell's cells are useful in medical practice chiefly for charging accumulators.

56. **Groves' and Bunsen's batteries.** — These have for their depolarizer strong nitric acid. In the former the positive pole is a platinum plate, in the latter a plate or rod of hard gas carbon. In both batteries the positive pole is contained in a porous pot filled with strong nitric acid and this is surrounded by the zinc plate contained in a vessel filled with dilute sulphuric acid (fig. 9). The action of the battery may be looked upon thus :—At the porous partition the electrolysis is taken up from the dilute sulphuric acid by the nitric acid and the hydrogen that would be given off at the platinum or carbon pole is oxidised by the nitric acid to water, the acid being reduced and decom-

posed with production of nitric oxide. This is partly dissolved in the rest of the nitric acid, giving it a green colour, and part escapes into the air where it combines with oxygen to form the corrosive red fumes of the higher oxides of nitrogen. These fumes and the general uncleanliness and corrosiveness of nitric acid form the greatest objection to the use of this battery. If it can be set up in a draught cupboard or outhouse it is useful for recharging accumulator cells.

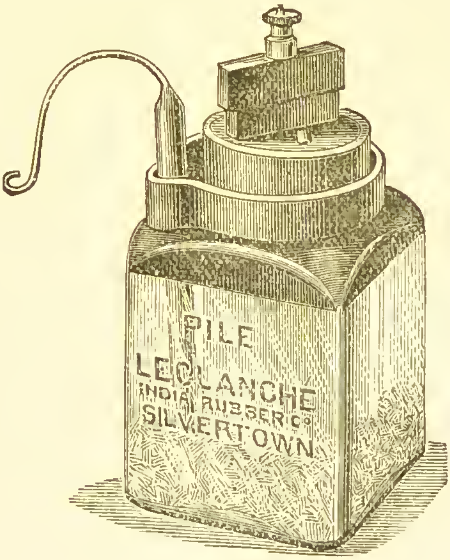

FIG. 11.—Leclanché cell.

57. **The Leclanché battery.**—The cell most universally used for medical work is the Leclanché battery, the exciting solution in which is a saturated solution of ammonium chloride (sal ammoniac) fig. 11. The negative pole is a zinc rod and the positive pole a carbon plate or rod. This is surrounded by the depolarizer, manganese dioxide, which is able slowly to oxidise any hydrogen evolved by the action of the cell. In the

older forms of Leclanché cell the carbon pole was packed tightly in a porous pot with fragments of carbon and granular manganese dioxide. The more modern form of cell has no porous pot, and thus its internal resistance is reduced, but the carbon has attached to it a conglomerate formed of manganese dioxide and carbon pressed into blocks. This form is called the agglomerate type. The addition of a little chlorate of potash to the exciting solution has been recommended in the proportion of one part chlorate to three of sal ammoniac. It is possible that this addition may help to make the depolarizing action more complete.

The chemistry of the cell cannot be expressed in any simple manner. When the circuit is open there should be absolutely no action between the solution and the zinc (local action) and this makes the cell a very economical one, but when the circuit is closed the zinc is dissolved, forming a double chloride of ammonium and zinc, and an oxychloride of zinc while ammonia and hydrogen are evolved at the carbon pole. If only a small current is taken from such a cell the manganese dioxide does its work and the cell is fairly constant, but if much current is used the oxidising action of the manganese dioxide is unable to keep pace with the evolution of hydrogen and the cell becomes polarized, though it recovers completely if left for some hours on open circuit. The electromotive force of a new Leclanché cell is about 1·5 volts. The advantages of the battery are that it possesses great power of recovery, has no appreciable local action and may consequently be left for months at a time without attention, and has a fairly high electromotive force. Against these we must set the fact that its electromotive force runs down very rapidly when it is called on to produce a current of any magnitude.

None of the cells in which dilute acid is used for the exciting liquid can be left to themselves in the way that Leclanché batteries can, for in all of them the local action would soon destroy the zinc if it were not removed from the acid as soon as the battery was done with, and on that account alone acid cells are not very suitable for medical purposes, since they require too much attention; means have been devised for facilitating the removal of the plates from the acid when the battery has been done with, but there still remains the difficulty of dealing with the liquids, especially during the transport of the battery from one place to another. Medical batteries must allow of being carried to patients' houses when necessary, and the ordinary open cells with acid liquids in them are most awkward; the liquid is easily upset and corrodes whatever it touches, consequently medical men are ready to make considerable sacrifices in other directions for the sake of a closed cell, in which the trouble of attending to the zincs can be got rid of, and in which there is no risk of upsetting acids. Accordingly, except for very special purposes, the Leclanché cell is almost universally employed, for in it the zinc can be left always in position without waste from local action, and the cell can be closed in with pitch or cement, to prevent any escape of the exciting fluids from within; these conveniences are purchased at the cost of a high internal resistance and of a tendency to polarization, but for most medical work these objections are not very serious, because the huge resistance of the human body reduces by comparison the internal resistance of the battery to an almost negligeable quantity, and because the amount of current required in most cases is only a few thousandths of an ampère (5 to 50 milliampères). Even when the por-

tability of the battery is not important the Leclanché element is still preferred, for once installed in a cellar or a cupboard, it can be left alone without attention for months or even years, and by the use of large cells instead of small ones, the internal resistance can be reduced, while the capacity of the cell for doing work can be increased. The Leclanché cell then is the one most commonly used for medical purposes, and its management, mode of action, defects and good qualities should all be thoroughly mastered once for all by those who intend to work at the subject of medical electricity.

Numberless modifications of this cell have been put upon the market at different times, but these have differed from the original type mainly in such details of construction as shape of cell, omission of porous pot, and shape of plates.* We shall further consider one of the modifications in treating of "dry" batteries (§ 58).

To preserve Leclanché cells in good order they must receive a little attention from time to time about once in six months or so. The larger sizes in glass jars can be easily inspected, and the condition of the zincs and the level of the liquid ascertained.

If the zincs are blackened they should be scraped and amalgamated, and the liquid can be renewed by adding water to replace what has been lost by evaporation. The cells must not be filled to more than two-thirds of their capacity. If the amount of work done by the battery has been large and the solution has become milky, it had better be withdrawn by means of a

* The most recent form is known as the Leclanché-Barbier cell. It is a good cell, and can be obtained in several sizes from Mr. Schall of 55 Wigmore Street, and other similar instrument makers.

syringe or a syphon, and fresh solution put into its place. The proportion of six ounces of sal ammoniac to a pint of water makes a solution of proper strength. The upper inch of the glass cells ought to be brushed over with vaseline or hot paraffin wax to prevent *creeping* of the salts. This is the formation of crusts of the sal ammoniac around the top of the cell, it is harmful because they may connect together two neighbouring cells, so closing a circuit, and wasting the battery.

When large crystals form in masses at the bottom of the cell and round the zincs it is time to take down the battery and set it up afresh. These crystals are a double chloride of zinc and ammonium, and are insoluble in water, but they can be dissolved in strong hydrochloric acid. When they have formed in the outer vessel, they have probably formed in the porous pot as well, and their presence there is not desirable, because they increase the internal resistance of the cell and block up the interstices of the carbon and manganese dioxide. When the battery is being renewed the liquid inside the porous pot should be poured off through the small holes at the top, and dilute hydrochloric acid (1 to 10) poured in and left for twenty-four hours, and after that the porous pot must be soaked for another day or two in water. If there is reason to think that the cells are worn out, they may be recharged with manganese dioxide and broken carbon, or better still they can be replaced by new ones. The management of the small Leclanché cells used in portable batteries is much more difficult, because it is impossible to see their condition ; one can do little beyond emptying out the liquid with a fine syringe and putting in fresh sal ammoniac solution in the same way from time to time, and to do even so much as this is a tiresome

operation. If the cells when new are charged with pure zinc chloride, 1 in 6, instead of with sal ammoniac, they will last a long time without the formation of the hard crystals, and can be recharged with fresh zinc chloride solution, slightly acidified with hydrochloric acid. Unfortunately, however, Leclanché cells as sent from the makers, have already inside them a charge of sal ammoniac, requiring only the addition of water to set them in action. It is of no use to charge these with the zinc chloride.

58. **Dry batteries.**—Of late there have been several

FIG. 12.—Hellesen's dry cell.

so-called dry batteries put forward and these are in many ways exceedingly convenient. These are sealed cells of the Leclanché type. They will work in any position and require no special attention whatever, but it must be remembered that all sealed forms of cell have a capacity for work strictly limited by the original charge of chemicals, and cannot be restored to action when run down by the addition of fresh exciting liquid. In most

of them the zinc plate is shaped like a canister and forms the containing vessel of the cell, it is packed with a paste of exciting material, and inside this is the carbon and manganese dioxide. Cells of this type can be obtained from the General Electric Co. (the E. C. C. Cell), and from Messrs. Siemens Bros.

The dry battery lately brought out by Messrs. Siemens Bros. and Co. under the name of "Hellesen's patent dry cell" (fig. 12) works very satisfactorily. Like the other dry cells it is a modified Leclanché battery as the poles consist of zinc and carbon and the exciting salt is sal ammoniac mixed with quicklime, while the depolarizer is manganese dioxide. They are made in several sizes, the smallest size, for portable medical batteries, weighs only eight ounces, and is a very good cell. They will last for a year and a half or two years with proper care, but after that time must be replaced by new ones. They cost eighteen pence apiece. The larger sizes are very good for working induction coils. A newer cell by the same firm known as Obach's dry cell is also recommended, but we are unable at present to speak about it from personal experience.

59. **Chloride of silver cell.**—The chloride of silver battery was invented in 1868 by Warren de la Rue and Hugo Müller, and modified and improved by Skrivanoff in 1883. It possesses some good qualities, but it is a rather expensive cell to buy. Unfortunately the silver chloride passes into solution after a time, and is reduced to metallic silver on the surface of the zinc. Local action then sets in, and the cell rapidly deteriorates.

60. **Lalande oxide of copper cell.**—This cell as modified by Edison consists of plates of zinc and copper; oxide of copper compressed upon the copper plate acts as depolarizer, caustic potash solution is the excitant. The

cells are said to be very constant, and can furnish large currents. There is little or no local action. Their electromotive force is low, ·8 of a volt, and they are not very suitable for a portable battery (Fig. 13).

61. **The sulphate of mercury battery.**—A battery that has been used for medical purposes, especially in the pocket induction coils sold by M. Gaiffe, of Paris, consists of plates of zinc and carbon in a solution of sulphate of mercury. In the apparatus mentioned above

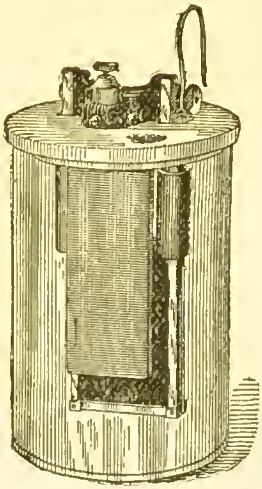

FIG. 13.—Edison-Lalande cell.

two small cells are generally supplied in the form of trays of gas carbon on which is placed a small quantity of the commercial sulphate of mercury, and a little water; the zinc plates are then laid on this and are kept from contact with the carbon by three vulcanite studs. The electromotive force is about 1·45 volts per cell.

Latimer Clark's standard cell is a form of sulphate of mercury cell, which is used in laboratory experiments,

but it requires the utmost delicacy in management, and is used solely as a standard for the comparison of electromotive forces; its electromotive force is 1·434 volts at 15° C.

62. **Stöhrer's battery.**—This battery, largely used in medical work, is a modified form of bichromate battery. The elements, zinc and carbon, are arranged in

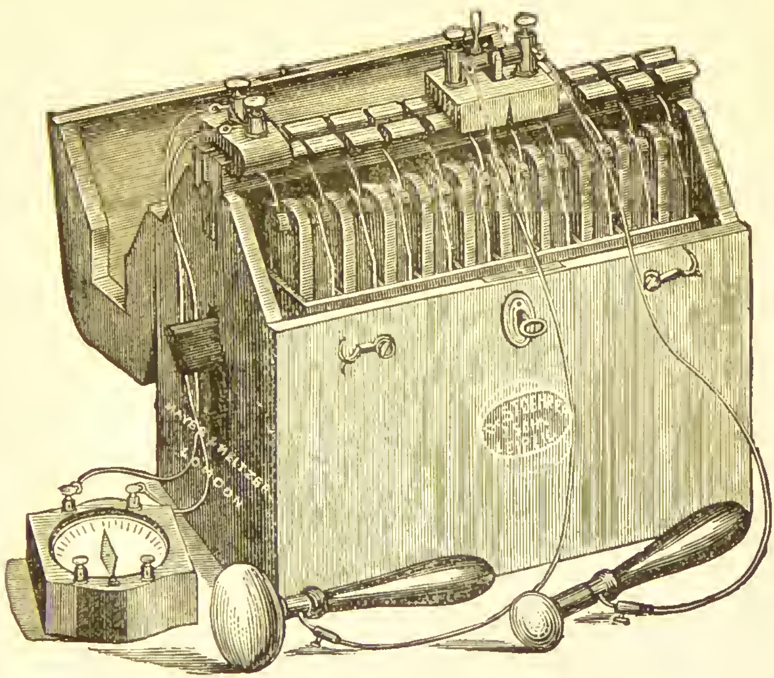

FIG. 14.—Stöhrer's battery.

a double row on a wooden bar, so that a double row of glass or earthenware cells containing the exciting fluid can be raised up to them in such a manner that the correct pairs of plates dip into each cell (see fig. 14).

The battery may be made up to contain 20, 30, 40, or even 60 cells, these form a double row in a strong

oak box, and a beam of wood with a deep channel cut in it extends from end to end of the box in the middle line; the pairs of plates are all suspended from this beam by stout brass rods, which convey the current from the cells to the travelling collector.

Cells can be taken up into circuit by twos, starting from the end of the box, where the cross connection occurs, and the beam carries numbers, 2, 4, 6, &c., by which the collector can be set to include the indicated number of cells. So when the collector is set at six, there are six cells in series in circuit, three being taken from each of the rows of cells, and the number of cells in circuit can be altered by steps of two at a time, so that any even number, from two upwards, can be included.

The collector which slides in the groove of the beam carries two flat brass springs which make connection with the brass rods from which the pairs of plates hang. From the springs the current is led through a commutator to a pair of binding screws, and from these the wires may be led to the place where the current is required. It may be noticed that Stöhrer's battery was originally designed for use with dilute acid only, as in Walker's modification of Smee's cell, but the addition of the chromic acid depolariser obviously improves its action.

The battery is not portable owing to the quantity of corrosive liquid in the cells, and it is very troublesome and difficult to keep it clean, and its zinc plates amalgamated. It is therefore becoming obsolete.

63. **Accumulators or secondary batteries.**—A so-called *secondary battery* in reality only differs from a primary battery of any of the types that we have been describing, in that when it is run down and exhausted

it may be renewed by driving an electric current into it and thus setting up an electrolysis that brings the chemicals used back to their former state, while in the *primary batteries* it is necessary to renew the whole of the chemicals. It is therefore a misnomer to speak of the "storage of electricity." There is no more actual storage of electricity in one of these batteries than in a

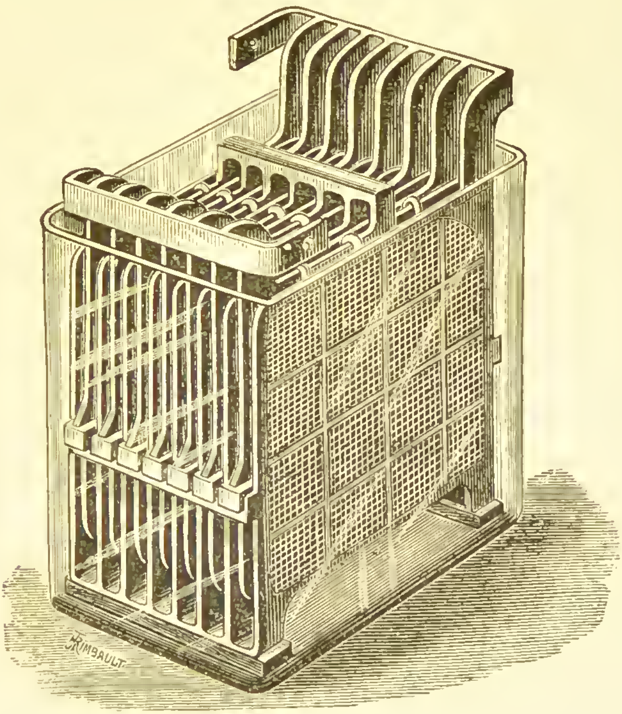

FIG. 15.—Accumulator in glass vessel, showing arrangement of plates.

primary battery. Either may be looked upon as a store of energy, and in both the energy stored is energy of chemical action. Secondary batteries are generally of one of two types, in both of which the plates are of lead. The older cell of the Planté and Faure type had porous lead plates, placed in dilute sulphuric acid as the elec-

trolyte; these cells then require "forming," that is, a current is passed through them for a certain time, and they are then allowed to discharge themselves through a resistance, they are then charged in the opposite direction and allowed to discharge again, and this process is repeated several times. The object of this "forming" process is to increase their capacity by the production of a layer of lead peroxide upon the plate which is positive, and of spongy metallic lead upon the negative. In the other and commoner type of cell, the plates are perforated grids of lead, or, in the latest cells, an alloy of lead which is stronger than the pure metal.

The holes in the positive plates are filled with a paste made of red lead or puce coloured oxide (peroxide) of lead and dilute sulphuric acid, which sets fairly hard in them. Those in the negative plate are filled with a paste of litharge and sulphuric acid. The plates, formed into "sections" of positive and negative plates arranged alternately, are placed in the cells, and these are filled up with dilute sulphuric acid, of sp. gr. 1·170, and they are ready for the first process of charging. This is called "forming" the cells, and consists in charging them for a very long peiiod, say about thirty hours. When a cell has just been charged it will be found to have an electromotive force of nearly 2·5 volts, but this quickly falls to about 2·2 volts, even if the cell is left on open circuit, and after a short discharge, the cell only gives about 2 volts. When the cells are discharging the electromotive force is maintained till about 75 per cent. of the ampère hours that the cell will give has been done, and then the electromotive force begins to fall again. However, as the batteries must never be discharged beyond this point this is no drawback to their use, but rather an advantage, as by the use of

a voltmeter such as is supplied for the purpose by the E. P. S. company and others, it is always possible to test each cell of the battery and discover when it requires recharging. It may be taken as a general rule that as soon as the electromotive force of a cell falls below 2 volts or 1·9 at the lowest that cell should at once be recharged. It would be out of place here to enter into the reasons for this. Suffice it to say that if it is not attended to higher sulphates of lead are liable to form in the cell which increase its internal resistance and decrease its storage capacity and the grids are liable to buckle and lose their paste.

It is not easy to give much idea of the storage capacity of these cells, but a well designed one should be capable of giving about 5 to 7 ampère hours per pound of lead.

The internal resistance of a storage cell is almost infinitesimal when it is in good order, and may generally be neglected in calculations concerning them unless a very large number are coupled up in series, since the current that may be taken out of the cell is limited by other considerations. It is found that the density of current (§ 38) in a storage cell should not exceed ·065 ampère per sq. cm. of positive plate. If this limit is exceeded, the paste is liable to leave the plates. It is not necessary to go thoroughly into all the troubles that may arise if accumulators are misused, it is sufficient merely to give a warning as to the modes of treatment that will certainly damage the cells. First and foremost among them is the practice of flashing the cells to see if they are in working order, viz., connecting their poles through a short piece of copper wire; this treatment produces a rush of current of considerable magnitude, and it tends to loosen the paste and set up dele-

terious sulphating in the cells. They should always be tested with a proper voltmeter or with a glow lamp of the right size. Next, when a large current is to be taken from the cells, *e.g.*, one approaching the maximum permissible current, the cells should not be suddenly turned on but "eased down" through a resistance. That is to say, if a large cautery is to be heated, a resistance should be included in the circuit which can be decreased till the required current is obtained. The cells must never be allowed to fully discharge themselves, they should be tested from time to time, and as soon as the electromotive force of a cell sinks to 1·9 volts that cell must be disconnected and recharged. Further information will be found in Sir D. Salomons' book, *The Management of Accumulators.*

The difficulties found in working with accumulators of the type having "pasted" plates has caused some makers to return to the original type of accumulator as invented by Planté, where no pastes of the oxides of lead is used. A cell called the Epstein cell is one of the best known of modern forms of Planté cell; it is said to work and to keep well; but it is not at present made specially to suit medical practice, and the plates used are very heavy.

The Lithanode Company* have another form of secondary cell which works well, and is made in many different sizes, some of which are admirably adapted for medical purposes, particularly for lighting small incandescent lamps, and for heating cauteries (fig. 16). Their cells are light and compact, and the company undertake all arrangements for recharging and maintenance at a small cost. They make small accumu-

* The Lithanode and General Electric Co., 64 Millbank Street, Westminster.

lators weighing only four ounces, which are likely to prove very useful for medical batteries whenever the recharging can be done without much trouble (fig. 17), and also smaller cells whose weight is only two ounces

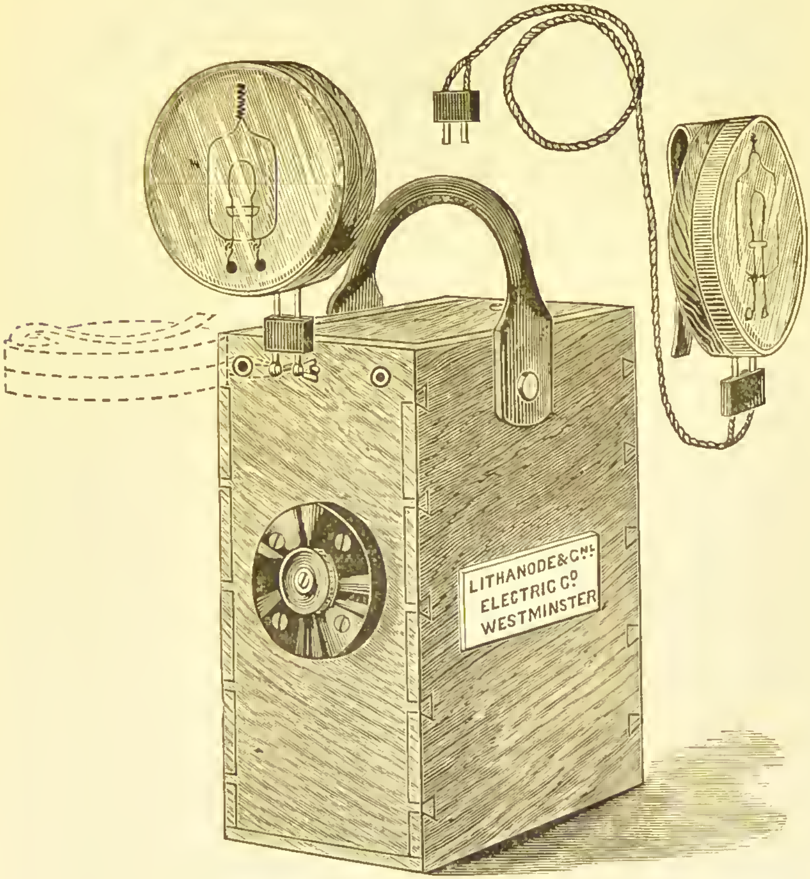

Fig. 16.—Five-cell lithanode cell with detachable lamp.

and a half. In the lithanode cells the positive plates consist of slabs of very dense lead peroxide enclosed in a metallic framework, and they are free from some of the faults common to the "pasted" plates.

64. **Table of batteries.**—The appended table of batteries may be of service. The internal resistance, though a most important factor in calculations as to the discharging rate of a cell, is so indefinite a quantity,

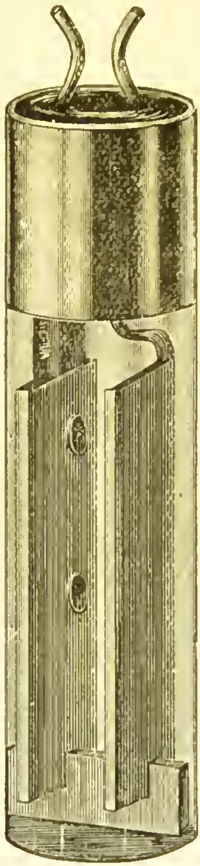

FIG. 17.—Lithanode testing cell.

and varies so much with the size, nature, and plan of construction of the cell, that it is difficult to do more than indicate very roughly its approximate value. An internal resistance which at all nearly approaches one ohm makes a battery useless for cautery purposes.

A Smee's battery in which the plates are one centimetre apart and ten by five centimetres in area would have a resistance of about ·05 ohm as calculated from

TABLE OF BATTERIES.

NAME	ACTIVE PLATE	EXCITANT	DEPOLARIZER	PASSIVE PLATE	APPROXIMATE ELECTRO-MOTIVE FORCE, VOLTS
1. Smee	Zinc	Dilute sulphuric acid, 1-8	None	Platinized silver	·8
2 Bichromate	"	Dilute sulphuric acid, 1-8	Chromic acid	Carbon	1·9
3. Sulphate of Mercury	"	Dilute sulphuric acid, 1-20	Acid sulphate of mercury	"	1·5
4. Daniell	"	Zinc sulphate or dilute sulphuric acid, 1-12	Copper sulphate.	Copper	1·079
5. Bunsen	"	Dilute sulphuric acid	Strong nitric acid	Carbon	1·9
6. Edison-Lalande	"	Potassium hydrate 40 per cent.	Cupric oxide	Copper	·8
7. De la Rue	"	Ammonium chloride saturated solution	Silver chloride	Silver	1
8. Leclanché	"	"	Manganese dioxide	Carbon	1·48
9. Hellesen	"	Ammonium chloride and lime	"	"	1·5
10. Secondary battery.	Lead	Dilute sulphuric acid, sp. gr. 1·170	Lead peroxide	Lead	2

the specific resistance of the acid used, but owing to real rise of internal resistance and fall of electromotive force due to polarization the apparent internal resistance when in use is much greater. The resistance of the bichromate cell depends upon its size and make, generally speaking in the types manufactured for

cautery heating and for lighting it is made as low as possible and is about ·1 ohm. The resistance of a Daniell's cell depends on its size and the thickness of the porous pot used and varies from about ·3 to 3 ohms. A quart Grove or Bunsen cell has a resistance of about ·15 ohm. The Edison-Lalande battery is made in several different sizes, in the larger forms the internal resistance may be brought as low as ·05 ohm. That of a Leclanché cell varies from about ·5 in the largest sizes to two, three, or five ohms in the smallest ones. The internal resistance of the various dry cells is given by the makers as from ·5 to 1 ohm according to size. The secondary batteries all have a very low internal resistance indeed, according to the number and size of the plates. Thus it will be seen that it is advisable for every owner of a battery to determine its internal resistance for himself.

Cells which have a low internal resistance are much more easily run down by any accidental short circuiting than those with a high resistance. If an accumulator cell with an internal resistance of ·05 ohm be short circuited, it may discharge at a rate of 40 ampères, which will very quickly exhaust it, and most likely damage it seriously as well.

65. **On the choice of a battery.**—Medical men are frequently asking for advice as to the choice of a battery. They would like to have one which will answer all the purposes for which it can possibly be required, which is portable and cheap, and does not require frequent attention. At present it is not possible to combine all these properties in one battery. Two separate batteries at least are required. In many cases it is more convenient to bring the patient to the battery than to carry a battery to the patients, but where this

is not possible, portability must be made the first object. Small and portable batteries are sold by the various instrument makers consisting of from 25 to 40 cells

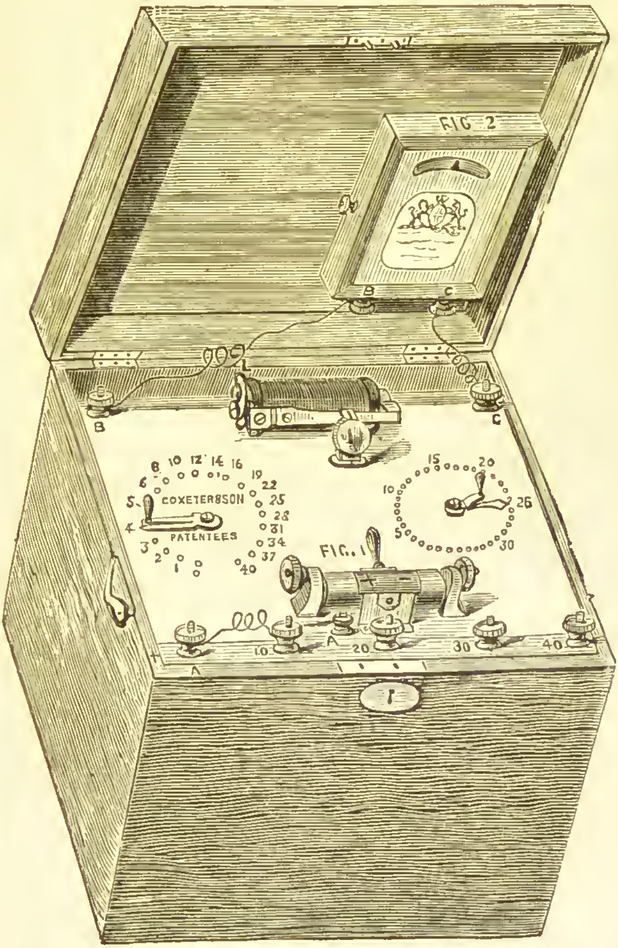

FIG. 18 —Coxeter's combined battery.

arranged in a case and fitted with commutator, current collector, galvanometer and induction coil. These are quite suitable for testing the reactions of nerve and muscle, for general medical treatment and for electro-

lysis. The cells used are most commonly small Leclanché or "dry" cells. Owing to their small size

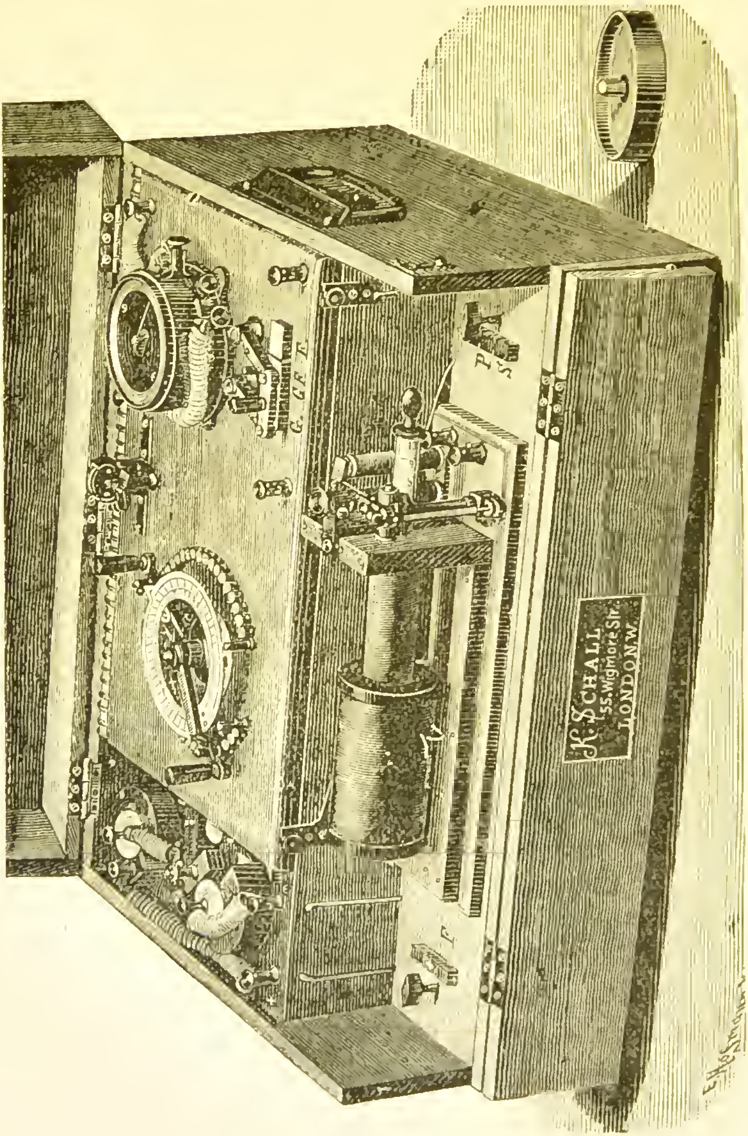

FIG. 19.—Schall's combined battery.

their capacity is not large and if any considerable current is required to be taken from them, the plates may prove unequal to the task and become polarized or even permanently damaged thereby. With proper treatment they may be counted upon for a year or two, and then will require recharging or renewal. The best plan perhaps is to use small dry cells, and renew them altogether when exhausted. As they cost only about eighteenpence per cell this is not a heavy charge for

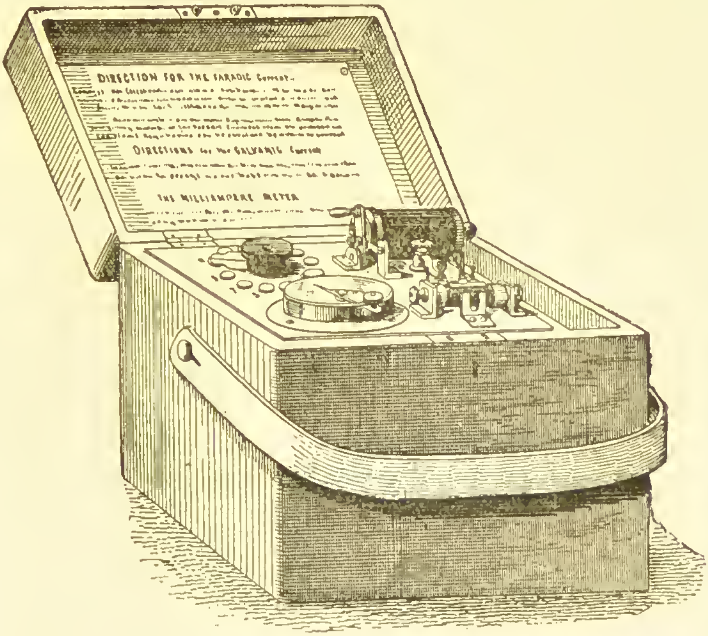

FIG. 20.—Miller and Woods' battery.

maintenance. For working the induction coil two cells of larger size are fitted; these will run down more rapidly than the others and require renewal more frequently. Mr. Coxeter and Mr. Schall have both given much attention to this form of battery and their catalogues may be consulted by those wishing to purchase

anything of the sort. Messrs. Miller and Woods, 2 Gray's Inn Road, Holborn, also make a very good and useful battery for general medical purposes at a moderate price.

In addition to the batteries just described, a separate one of a different kind is required for heating cauteries and for electric light instruments. A four cell accumulator arranged with a switch to connect the cells into two pairs in parallel, or into four cells in series, and provided with an adjustable resistance is the best battery for fulfilling these requirements, unless the recharging is an obstacle. In that case a four cell bichromate battery of large size, with proper connections, will serve the same purpose.* If preferred, one battery may be used for the cautery and another for electric light instruments, but it may be taken as a good general rule not to have too many batteries. Thus there is no need to have a fixed installation in the consulting room as well as a portable combined battery, for the latter will serve at home as well as in the houses of patients, and as all battery cells tend to deteriorate on keeping whether they are used or not, there is twice the cost of maintenance with two batteries that there is with one. Naturally it is convenient sometimes to have a fixed installation of large cells at home, as well as a portable set; but it is by far more economical and less troublesome to have one battery, and to get as much work out of that as is possible before the cells have become spoiled through keeping; for spoil they will whether used or not.

An exception may be made in favour of an induction coil set. The induction coil is more often required for purposes of treatment than a constant battery; and it

* K. Schall, 55 Wigmore Street, price £6.

is a convenience to have a light-weight induction coil, for then the labour of transporting a heavy combined battery will sometimes be saved.

It may be useful here to suggest the best types of cell for the various purposes to which they may be put by medical men:—*For general medical purposes* of testing and treatment, 25 to 30 dry cells or medical Leclanché cells. *For working induction coils*, one or two dry cells of larger size, or a bichromate cell. *For medical lamp instruments*, four or five cells of lithanode or other secondary battery, or six large bichromate cells, or large dry cells. *For cautery purposes*, two accumulator cells, or four large bichromate, or Edison-Lalande cells. *For recharging accumulators*, Edison-Lalande cells, bichromate cells (especially the form known as the Weymersch battery*) or Bunsen or Daniell cells.

66. **Care of batteries.**—It would seem to be advisable before leaving the subject of the battery to say a little as to the care of a battery. In the closed cells, no attention need be given so long as the electromotive force remains at its normal value, except that the cells must not be left short circuited and should be kept clean and insulated from one another, while care must be taken never to draw from them a larger current than they are intended to give. Of course when the electromotive force shows any considerable signs of permanent falling off it is time to have the cells renewed. Leclanché batteries also require but little attention, beyond occasionally filling them up to the proper level with water to make up for loss by evaporation. Should the exciting liquid show a tendency to creep up the sides of the cells this should be stopped. The usual

* Messrs. Sharp and Kent, 34 Victoria Street, E.C.

method is to coat the upper part of the cells with paraffin wax for a depth of an inch or so inside and out. The Edison-Lalande cell works steadily until exhausted. New plates must then be fitted and new solution prepared, and the oil upon the surface of the liquid must always be renewed at the same time, to protect the caustic potash from the air. This battery is sent out with plates for renewal and complete instructions for use, and is easily kept in order.

The batteries that really need attention are those in which the exciting liquid is dilute acid, so that what is here said on the subject will apply to the following types, Smee's, Grove's, Bunsen's, Daniell's and bichromate cells and also to a certain extent to sulphate of mercury batteries. The first and most important point to be considered in all these cases is that all contacts shall be bright and clean so that there is good metallic connection wherever it is wanted, and too much trouble cannot be expended on this. An old file and a piece of coarse emery cloth well applied will do wonders here. Then the zincs must be well amalgamated. They should be scraped and brushed to show a moderately clean surface and wetted with dilute acid, and then mercury to which a little solution of nitrate of mercury or a few drops of nitric acid have been added should be well rubbed in with a piece of stick; a piece of firewood somewhat rotten and shredded by the action of the acid does very well. The surface of the zinc when properly amalgamated appears to be wetted by the mercury at every point. If this is properly carried out there will be little loss from local action in the battery. In filling Bunsen's and Grove's batteries care should be taken that the nitric acid does not spill into the compartments for the zinc, and after use the liquids may be

stored separately for future use until exhausted. These batteries should always be dismounted when done with and carefully cleaned before storing away; a little trouble spent here will save a great deal when the battery is required again. Bichromate cells want constant attention. It is not easy to tell when the exciting liquid is exhausted and as it is very opaque it is also difficult to tell if there are many crystals formed in it. If the battery fails and the liquid is dark green it must be renewed; if it is still orange, a dose of strong sulphuric acid will restore its action for a time. If sodium bichromate be used instead of the potassium salt the tendency to crystallize is much reduced since the sodium chrome alum is far more soluble than the corresponding potassium salt. In any case the carbon plates should be occasionally soaked in warm water and sometimes brushed with a hard or wire brush. On no account should the zincs be left in the chromic solution when not in use as it attacks even pure zinc with great facility.

Sulphate of mercury batteries are messy to use and should always be well cleaned. It is well to remember too that mercury contaminated with acid salts of mercury amalgamates most metals more easily than pure mercury. It is perhaps hardly necessary to observe that all gold ornaments or coins must be carefully kept from contact with mercury.

To charge an accumulator from a primary battery, the latter must have an electromotive force greater than that of the cells to be charged. For a two-cell accumulator, five Daniell cells, three bichromate, or Bunsen cells, or seven Edison-Lalande's are required. The charging cells must be large; the operation is as follows:—The primary battery having been freshly

charged, and tested to see that it is in good order, it must be attached to the accumulator, positive pole to positive pole, and negative to negative. Current will then pass to the accumulator from the battery so long as its electromotive force keeps up above that of the secondary cells. The current will slowly diminish as the primary cells run down; when the electromotive forces of the primary and secondary cells are in equilibrium no current passes in either direction; if the primary cells run down more the current will set in the other direction and the accumulator may discharge itself through them and thus defeat the object of the charging operation.

The operation must accordingly be watched and stopped before the charging current has fallen to zero. A suitable ammeter (Chap. IV.) will show the magnitude and direction of the current which is passing. By noting the magnitude of current at intervals during the charging process, an idea is obtained of the amount of the charge. For example, suppose the duration of the charge be six hours, and the current during the first hour be three ampères, during the second and third hours two ampères, during the fourth one ampère, and during the fifth and sixth half an ampère, then the charge will be in ampères for each hour, 3, 2, 2, 1, $\frac{1}{2}$, $\frac{1}{2}$, or 9-ampère hours.

The method of charging accumulators from the electric light mains is described in § 74. See also Mr. J. T. Niblett's little book, *Portative Electricity*,* for much valuable information upon the whole subject of the management, care and charging of small accumulators.

The utmost vigilance must be perpetually exercised to guard against accidental or intentional short circuit-

* Biggs & Co., Salisbury Court, Fleet Street.

ing of any battery. Few batteries will stand short circuiting for many minutes; the dry batteries often used in medical practice are particularly sensitive to it, their life is shortened and excessive polarization takes place from which in all probability they never completely recover. Short circuiting may easily occur if the electrodes are carelessly thrown down after use, and should happen to lie in contact with each other.

When a battery has been dismounted and put together again, especially if it has many complex connections, there is a danger that the positive pole may have been accidentally connected to the binding screw marked negative and *vice versâ*. This is sometimes the case even when the repairs have been done by an instrument maker. This is an important point because confusion of the poles may lead to serious mistakes and even to injury to the patient. All risk can be done away with by the use of some method of testing the polarity of the electrodes. Pole testers are made by electrical instrument makers and a neat form is sold by Messrs. Woodhouse and Rawson. It is very easy, however, to improvise such a thing. A piece of wet litmus paper on a sheet of glass, will show by changes in colour at the electrodes which is the positive and which the negative pole. The ends of the circuit must be rested on the paper for a few moments, electrolysis will take place and the litmus will be reddened by the acid liberated at the anode or positive pole, and will turn blue at the kathode or negative pole. Many other reagents have been proposed, a solution of phenol phthalein in dilute alcohol contained in a vessel, into which the poles can be dipped answers very well, giving a purple red colour at the kathode or negative pole.

67. **The induction coil.**—One of the most interesting

of the early observations in connection with electro-magnetic induction was, that shocks and sparks could be produced from a single galvanic cell if its circuit contained spiral coils of wire. Indeed, it is possible that Faraday's researches into the phenomena of induction may have been started in that direction by a question asked of him at the Royal Institution, as to why a shock was felt when a circuit containing an electro-magnet was broken, although no shock was felt if the circuit contained no magnet nor coils of wire. In § 46 it has been mentioned that these effects depend upon the self-induction of the circuit ; and very shortly after the publication of the researches of Faraday and of Henry in 1831 and 1832, the subject was taken up by others, and coils were made by Page, Sturgeon, Callan, and others, which were the prototypes of the modern induction coil.*

The peculiar physiological effect or shock which these induction coils produced soon led to their application to medical treatment, and in 1837 a machine contrived for this purpose by a Mr. Clark, was figured† in Sturgeon's *Annals of Electricity*. Others quickly followed, and the drawings of the period commonly represent these coils as fitted with handles for patients to grasp, showing that their power of giving shocks was recognised as an important feature. By the introduction of the separate "secondary" coil, and of the automatic contact breaker, the induction coil acquired its modern form, and the researches of Duchenne into the different physiological effects of long and short coils was an application of the

* For a full and interesting account of the early history of the induction coil, see Fleming, *The Alternate Current Transformer*, London, 1892.

† See Fleming, *op. cit.*

principles already foreshadowed clearly by Henry's experiments with long and short wire spirals.

Since then the medical induction coil has undergone many modifications at the hands of ingenious instrument makers, but few of these modifications have been of much value, because the principles determining the physiological action of the coils has received but scant attention. Perhaps the acme of absurdity has been reached in an American coil, guaranteed to "give ten different qualities of electricity."

It is convenient to consider the phenomena of electromagnetic induction as depending on the magnetic field of force (§ 30), which exists round a wire carrying a current. It is easy to show that when such a wire is wound into a helix or solenoid, this behaves as a magnet, and the magnetic lines of force of a straight helix are arranged precisely like those of a bar magnet, *see* fig. 3. If a bar of iron is inserted into the helix, the magnetic permeability of that portion of the magnetic circuit becomes increased, because iron conducts magnetism several hundred times better than air does, and consequently more lines of force will traverse the helix for the same strength of current in the wire, and the magnetism of the helix will be increased. The magnetic field set up in the helix at the moment of closing the battery current reacts upon the wire and produces in it a wave of opposing electromotive force which retards the growth of the current so that it does not instantaneously reach its full strength, and the collapse of the magnetic field at the moment of breaking the current also sets up a wave of electromotive force in the wire which strengthens the battery current and shows itself by a bright spark at the place where the circuit is broken.

In its simplest form the induction coil consists of a coil of insulated wire wound upon a reel or bobbin with an arrangement, usually a vibrating spring, for automatically closing and opening the circuit. When a current passes through it the spring comes into play, and the current is periodically established and interrupted, and so the magnetic field of the apparatus is caused to vary with every make and break of contact, and induction currents are produced in the wire coil. The induced current at break can be led off by properly arranged conductors and is known as the primary current, or the extra current; the other does not leave the apparatus but expends itself in the closed circuit formed by the coil and the contact breaker. The primary current is therefore a series of impulses or waves, all passing in the same direction, and corresponding in time and frequency to the interruptions of the contact breaker; each wave is due to a sudden rise of electromotive force in the wire, followed by a more gradual fall, the whole time of each wave being a very small fraction of a second, and varying considerably in different coils.

The secondary current of an induction coil, as its name suggests, is derived from another entirely independent coil wound upon the same bobbin as the primary coil. Being in the same magnetic field as the primary coil it is acted upon in the same way, but the effects produced in it are not quite the same, because they are quite free from the battery current which flows in the primary coil. In the secondary coil there is an induced electromotive force corresponding to the rise of magnetism and an opposite electromotive force corresponding to its fall. Both of these give rise to currents through an external circuit, and because they are in op-

posite directions the currents from the secondary coil are said to be alternating. They are not exactly alike in all respects, although the total flux of electricity is the same in each, for the electromotive force at the break of the primary circuit is higher, and the duration of the wave is shorter, than at make, because, as has been seen, the rise of magnetising current in the apparatus is more gradual than its fall.

The electromotive forces developed by induction in the primary and secondary coils vary very much in different instruments. In both coils the electromotive force is much higher than that of the battery which supplies energy to the apparatus, and this is the reason why the shocks from a coil are so much stronger than those that can be felt from the battery which drives it.

Almost any electromotive force can be obtained from a secondary coil by a suitable mode of construction, because other things being equal, the electromotive force is increased by multiplying the number of turns of wire in the coil, as the total electromotive force in the coil is the sum of the electromotive forces developed in the individual turns which compose it.

Fig. 21 is a plan of the arrangement of the wires in an induction coil, and fig. 22 shows an actual coil. The lettering is the same in both of the figures. One pole of the battery is connected to the binding screw A. The current then passes by the adjusting screw B, the vibrator H, and the support K to the horse-shoe magnet D. After traversing this the circuit gives off a branch to the binding screw P, and is continued to the primary coil, EE, the return wire from which again gives off a branch to the second binding screw at P, and is then continued to the other pole of the battery. The two binding screws at P are thus in

connexion with the two ends of the primary coil, and by means of electrodes attached to them the patient may

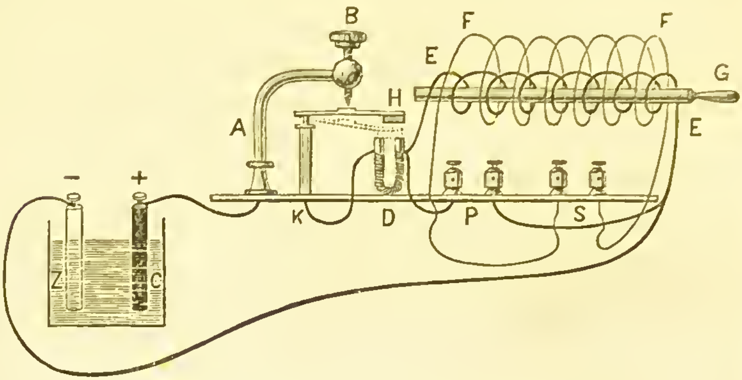

FIG. 21.—Arrangement of wires in an induction coil.

be treated with the primary current of this coil. The

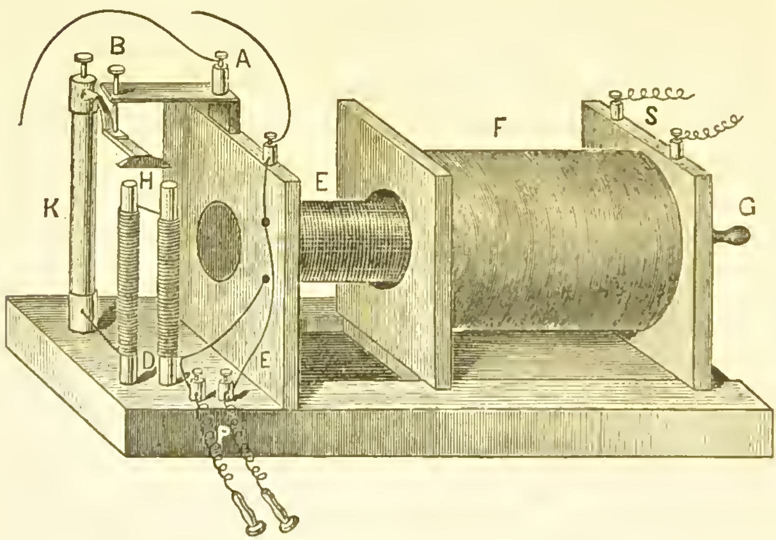

FIG. 22.—Induction coil.

secondary coil F is wound on a separate hollow bobbin and has its terminals at S. This bobbin is made to

slide like a sledge on guides so that it can be made to approach or recede from the primary coil. At G a handle is seen attached to the iron core which can slide in and out of the primary coil, and so further regulate the induced electromotive force set up in both the primary and secondary coils, by varying the strength of their magnetic field.

Another and somewhat neater form of sledge coil is shewn in fig. 23. The general plan of construction is the same as in the last figure, with the addition of divided scales by which the relative positions of primary, secondary, and core can be recorded and results veri-

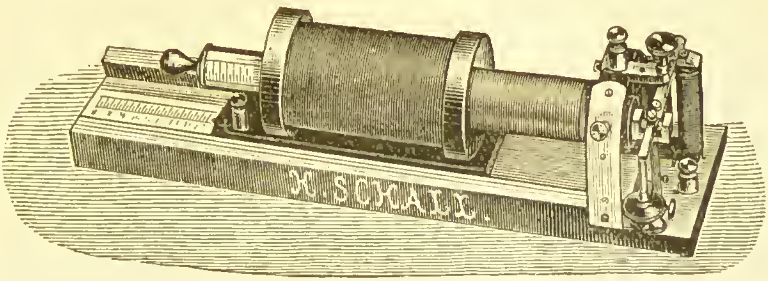

FIG. 23.—Induction coil.

fied. It must be borne in mind that the readings of the scale are not at all in proportion to the electromotive force or the current induced in the coils, they merely make it easy to reproduce a given condition at will.

The mode of action of the automatic vibrator or contact breaker is clearly shown in the figures. The electro-magnet by drawing down the spring H breaks the circuit at the point of the screw B, whereupon the attraction of the electro-magnet ceases and the spring is released, and flying up re-establishes the circuit; the action is then repeated, and the spring is kept in constant movement. By turning the screw B, the pressure

upon the spring and its rate of vibration can be modified. Instead of the separate electro-magnet it is easy to utilise the magnetism of the iron core for working the contact breaker, and this is done in those patterns of medical coil which have a fixed core; but in these coils some mode of regulation other than that of a sliding core is required.

In order that the coil may be used for medical purposes there must be some method of regulating its strength. The following methods are in actual use in medical coils:—

1. By the use of a sliding core to vary the strength of magnetic field in the coils.

2. By the use of a metal tube to slide over the core and so shield the coils from its action.

3. By the use of a secondary coil (sledge coil) which can be brought into stronger or weaker parts of the magnetic field.

4. By a switch for progressively taking up into the circuit greater or lesser portions of the coils.

The variety of coils in the market is very great, and they can be had either separate or fitted up in a box with a battery to drive them, and with a drawer to hold wires and electrodes; this is convenient, as it makes them more portable. An inspection of an instrument maker's illustrated catalogue, or better still of his stock, is the quickest way of becoming familiar with the types of coil in general use.

In choosing an induction coil the points to be attended to are as follows:—

First, to see that the vibrator works smoothly and evenly; this is very important, as many coils are defective in this respect, and give an irregular series of shocks of unequal strength, which is unpleasant for the

patient; before buying a coil it is a good plan to have it set in action, and to test it upon one's self. In this way it is easy to learn whether it works evenly; and, secondly, whether it permits of satisfactory regulation of its strength; thirdly, the coil should be quiet in action; fourthly, it should not require a large current, or else the cell used to drive it will require frequent renewal.

The induction coil is most commonly used to excite muscular contraction, either for purposes of testing or for treatment, but it is also used for its action upon sensory nerves. In the first case a low electromotive force is best, but for the latter a high electromotive force is needed, and in the best instruments two separate and interchangeable secondary coils are provided, one of a smaller number of turns of wire, and one of a very large number of turns, then either coil can be used as the case under treatment requires. Duchenne showed that the physiological effect of a coil of fine wire with many turns, differed from that of a short coil of few turns and thick wire, and his observations on this point may be expressed in modern language as follows:—With a short coil of two or three hundred turns, the electromotive force is low, but it is sufficiently high to excite contractions in the muscles if the skin be properly moistened. A long coil of many turns, two or three thousand, gives a high electromotive force, and when applied to the surface of the dry skin, with dry electrodes, it acts powerfully in spite of the great resistance offered by this mode of application. It is therefore useful in cases in which the short coil will not act.

On the other hand, the long coil is less useful for stimulating deep seated muscles, because it has a high resistance and a still higher impedance, which behaves

as an enormous additional resistance, and therefore its available electromotive force may be several hundred volts when the external resistance is very high, and yet may be comparatively low through a resistance like that of the well moistened skin. This may be compared to the behaviour of a galvanic cell of high internal resistance, whose available voltage for a circuit of low resistance may be only a small fraction of its electromotive force on open circuit (see § 49).

A particular secondary coil was tested by means of an electrostatic voltmeter, and the potential difference at its terminals came out at 89 volts. With a non-inductive external resistance of 1000 ohms, in shunt to the voltmeter, the potential difference fell to ten volts.

Another way of expressing the difference between long and short coils is to say that the short coil gives a lower voltage but a larger current, while the long coil gives a high voltage and only a very small current; the large current is able to influence deep muscles because it is not so much dissipated by diffusion through the tissues as in the case with the small current. And, on the other hand, the small current of the fine coil makes itself sharply felt at the point of entry through the skin, but is scattered by diffusion through the underlying tissues, and there is not sufficient density of current in the muscles to affect them. The fine coil should be used with a wire brush electrode, or other electrode of small surface, as this concentrates the current at the points of contact, and produces effective stimulation there, with little or no effect upon parts which are further removed.

Most of the coils in common use have intermediate properties, because the number of their windings is neither very small nor very great, and they are there-

fore not so well suited for the special purpose of stimulating the sensory nerves of the skin or the mucous membranes, without affecting the deeper parts at the same time. Duchenne has maintained that for the treatment of neuralgic pains the use of a current from a short coil is injurious, because it produces muscular contraction, and affects the deep structures, whereas the action should be limited to the surface, and patients will usually say that the pain is increased by the treatment if a short coil is used.

68. **Long and short secondary coils.**—The difference between a short coil of thick wire and a long coil of fine wire, depends very much more on the number of turns than on the diameter of the wire, for the ohmic resistance of the wire is only a small part of the total impedance of the coil. One secondary coil can therefore be made to take the place of two or more separate coils, if by any means the number of turns in actual use can be varied. This may be done by tapping the secondary coil in several places, and bringing out a wire from each point tapped to a separate binding screw. Coils of this kind can be had, in which one-third or two-thirds, or the whole number of the turns, can be used at will.

It is difficult to specify precisely what is the most suitable number of turns to give the short coil or long coil effects. In Duchenne's instruments the short coil seems to have had about 500 turns, and the long coil about 4000, but this is only a guess, as he merely states the lengths of wire used. But the number of turns is not the only factor concerned, and these figures will suffice to indicate the general proportion between the two coils.

69. **Frequency of interruptions.**—The interesting

results obtained from currents of very high frequency of alternation, which have been so ably developed by Elihu Thomson, Tesla, D'Arsonval, and others, has turned the attention of medical men to the study of the contact-breaker of the induction coil, and coils can now be bought with regulating devices to produce at will almost any rate within comparatively wide limits, as, for example, from one vibration to two hundred per second in Ewald's coil (fig. 24). In this the vibrator

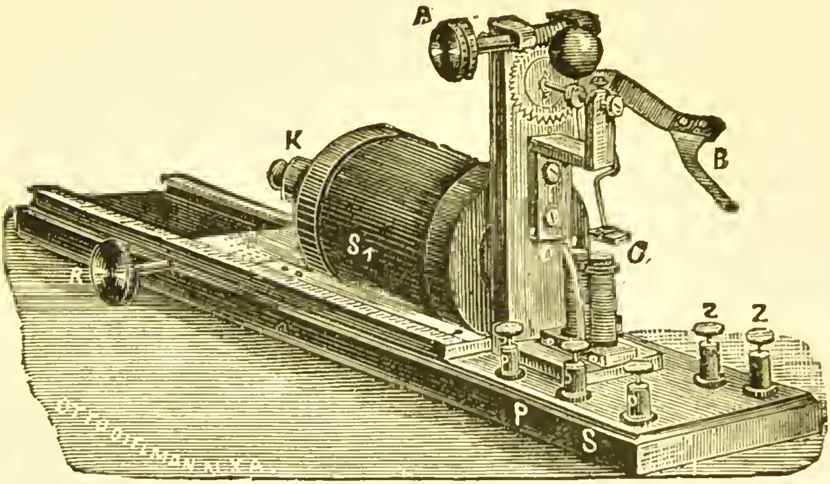

Fig. 24.—Ewald's coil.

has the form of a pendulum C, swinging between two springs, B and D. B can be altered in position by means of the screw A, and so controls the range of swing of the pendulum. Other coils again are fitted with a break, "the singing rheotome," which vibrates so rapidly as to emit a high pitched note, estimated at 500 per second. None of these rapid breaks, however, really attain to the conditions of true high frequency, which can be obtained with Leyden jar discharges, for these may have a period of oscillation equal to hundreds

of thousands or even millions per second, a rate which is a thousand times more rapid than that of the most rapid mechanical contact-breaker.

The average rate of vibration of the contact-breakers in common use in medical coils is about fifty per second.

Much work remains to be done before our knowledge of the influence of varying frequency of vibration can be considered satisfactory. It is very probable that the sensory nerves respond differently to vibrations of different frequencies. For instance, the heat vibrations emitted by warm bodies, and felt as a sensation of warmth, are at a rate of billions per second, but yet can easily be distinguished by the nerve endings from other forms of tactile sensation.

If the impulses are so infrequent that the muscle has time to relax between its successive contractions there is more commotion of the muscle, and greater discomfort than when it is maintained in a condition of tetanus; to produce this requires about 20 impulses per second.

The decreased effect of a coil whose contact breaker is vibrating rapidly, is in part due to the fact that the exciting current has not time to rise to its full value before it is broken again, consequently the magnetisation of the core, and the induction in the secondary coil do not rise so high as they would if the same coil were worked at a lower speed.

Duchenne preferred a rapid vibrator for acting upon sensory nerves, and for certain conditions of muscular atrophy and for stimulating muscles when they would not respond to slow interruptions, or had lost the muscular sense; for general purposes of muscular stimulation he advises slow interruptions, and prefers them in treating muscles paralysed by cerebral lesions, because

the slow stimuli acting less upon sensory nerves are less likely to set up reflex irritation of the seat of lesion in the skull. He believed that rapid vibrations might hasten the degeneration of muscle in certain cases. His slow vibrations were sometimes of the rate of one or two per second.

From 40 to 60 vibrations per second is a very suitable rate for testing and treating muscles; at higher speeds a peculiar benumbing effect makes itself felt when the electrode is applied over a sensory or mixed nerve trunk; this numbness is felt over the area of distribution of the nerve, and with it a strong but not painful vibration is felt all along that part of the nerve trunk which extends from the point stimulated to the periphery. It does not extend upwards along the nerve trunk, but is referred to its distal parts, very much as is the case with the ulnar nerve when it is struck or pressed at the internal condyle of the humerus, and produces pain or tingling in the ulnar side of the hand and fingers.

70. **Measurement of induction currents.**—The measurement of the electromotive force and current due to induction in the primary coil is complicated by the presence in the same circuit of the battery which drives the coil, and which exerts its own proper action upon any measuring instrument which may be put into the circuit. The secondary coil, however, is an independent coil and the effects of induction in it can be measured, but not by an ordinary galvanometer, for if the experiment be made it will be found that connecting a secondary coil to a galvanometer produces little or no effect upon the needle. The alternate impulses from the coil tend to deflect the needle first in one direction and then in the other, with the result that the needle

either remains quite still or else oscillates about its position of rest. If the magnetic needle be replaced by a small bundle of fine soft iron wires, these will be attracted by the coils of the instrument quite independently of the direction of the current in the coils, and in spite of the rapid changes of direction of the currents of a secondary coil, steady deflections of such a soft iron needle are obtained.

Instruments for measuring alternating currents are in common use in connection with electric lighting, where the currents to be measured are large, and descriptions of them can be found in most of the books dealing with that branch of electricity; but it is only quite recently that an instrument suitable for the small currents used in medical practice has been available. Mr. Giltay of Delft, Holland, makes an instrument, graduated in milliampères, which appears to answer the purpose admirably.* It depends in principle upon the attraction of a coil upon a soft iron needle, which is suspended between two coils in a position at an angle of 45 degrees with the axis of the coils. When a current traverses the coils, the needle tends to set itself in the axis of the coils, and its movements are made visible by means of a scale and pointer, or else by a small mirror, as in Thomson's reflecting galvanometer. Mr. Giltay also makes instruments, sensitive enough to give strong deflections with the minute currents produced by talking into a telephone receiver attached to the galvanometer.

The electromotive force of an induction coil can be best measured by an instrument invented by Lord Kelvin, and known as an electrostatic voltmeter. It is based upon the mutual attraction of two bodies oppo-

* *Ann. der Physik und Chemie*, Bd. 50, Leipzig, 1893 (figure).

sitely electrified, and has the advantage of using no current, and therefore it measures the electromotive force of the coil on open circuit. When the circuit of an induction coil is closed the voltage at its terminals falls away rapidly, particularly if it be closed through a low resistance.

Reference has already been made to a coil which indicated a mean electromotive force of 89 volts on open circuit, falling to 10 volts when its poles were joined through a conductor with a resistance of 1000 ohms. This observation shows the importance of measuring the electromotive force of a medical coil under conditions resembling those under which it is to be used.

The instrument known as the Faradimeter, which is a sledge coil driven by a current of regulated strength, and graduated in a scale of volts, is of very little use in medical practice.

The methods of measurement just indicated give readings of the mean currents or electromotive forces, and it is not always sufficient to know this, for the effects desired may be proportional, not to the mean current, but to the maximal current, or to the suddenness of its rise or fall. This is important in medical work; for the physiological effect in giving a shock "appears to depend in great part upon the suddenness with which the maximum current strength is reached. Of two discharges which reached equal maxima, that which arrived at it in the shortest time would be the most effective in producing shocks. The value of the maximum current strength is also important."*

It follows therefore that it is not enough to know merely the mean current or mean electromotive force of

* Fleming, *The Alternate Current Transformer*, vol. i., p. 180. London, 1892.

a coil, unless the maxima can also be arrived at. When the shape of the curve of the current (see next paragraph) is known, the maxima can be calculated from the observed magnitudes of the mean current, but if the shape of the curve is not known, then readings of the mean current or mean electromotive force are not a sufficient indication of the physiological effects of the currents.

71. **Graphic representation of currents.**—The changes in value of any varying quantity, as for example, electromotive force or current, can be represented graphically by a curved line, just as the variations in the body temperature of a patient are recorded upon the temperature charts used in clinical work.

If a horizontal line be drawn to represent periods of time, and if magnitudes of electromotive force be represented by distances above the base line (positive) or below it (negative) then an electromotive force gradually rising from zero to a maximum of fifteen volts positive, and falling again could be represented by the curved line ABC, fig. 25, and the continuation of the curve DEF, represents a reversal in sign of the electromotive force, and a fall to fifteen volts negative, followed by a return to zero, the period of time of the whole cycle being represented as one second. Similar curves could clearly be drawn to represent any values of electromotive force or current and any periods of time.

When the shape of the curve is known the electromotive force at any instant can be readily determined by plotting out the curve, upon paper suitably ruled with lines (squared paper), and conversely curves can be constructed by observing a sufficient number of instantaneous values and marking them out on the paper and drawing a line to connect them.

The curve (fig. 25) represents the gradual rise and fall of the electromotive force from a properly constructed alternate current dynamo machine, and may be taken as approximating very closely to the kind of curve of the alternating system of electric light supply, and with such a curve the ratio of maximum current to mean current is as 1 to ·637, or as 1·57 to 1, if the mean be taken as unity. A curve of this kind is known as a simple periodic curve, or a sine curve, and the current from an alternating current dynamo is often spoken of as a sinusoidal current. Owing to the gradual ascent

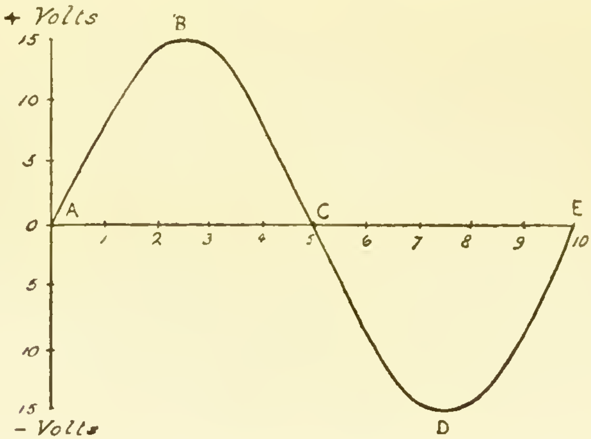

FIG. 25.—Graphic representation of a steadily varying electromotive force.

and descent of the wave, the physiological effects are somewhat different to those of currents which rise and fall more abruptly. Of late the physiological and therapeutic effects of sinusoidal currents have been studied particularly by M. D'Arsonval and MM. Gautier and Larat,* and they will be dealt with in a later paragraph.

* See *Revue internationale d'électrothérapie*, 1892-3, vol. iii. and iv., *Archives d'électricité médicale*, 1893-4, vol. i.

Although the shape of the curve of the medical induction coil is not fully understood, still we are not without some information upon the subject. Many curves, most of them wrong, have been drawn from time to time on theoretical grounds to represent them, but actual tracings have also been taken, one or two of which are reproduced here from a paper by Dr. Kellogg* in which the method of doing so by means of an instrument devised by d'Arsonval is fully described.

Fig. 26 shows the discharge curves of a secondary coil when the battery current was made and broken by

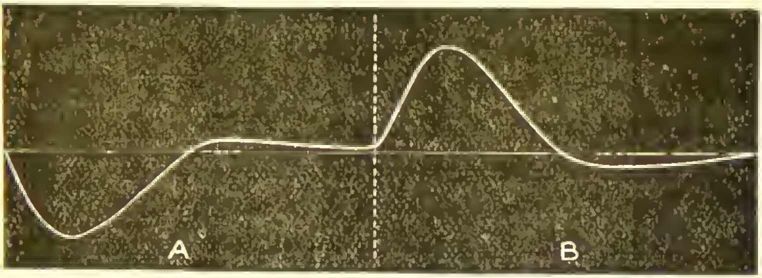

FIG. 26.—Secondary coil discharge. Battery current made and broken by hand A. Wave at make. B. At break (Dr. Kellogg).

hand. Here the wave at make is completed before the reverse current of break commences; the wave has a gradual and uniform contour both at the make and break.

Fig. 27 shows a tracing taken with the vibrating contact breaker in action, the make discharge commences as before, but the break discharge following too quickly after it, has altered the contour of the tracing, which now shows the break discharge as starting from the top of the wave of the make discharge, instead of from the line of zero potential. This means a reversal more or

* *The International System of Electrotherapeutics*, edited by Dr. Bigelow (F. A. Davis & Co., Philadelphia), 1894.

less abrupt of the direction of the current, and a greater sensation of shock.

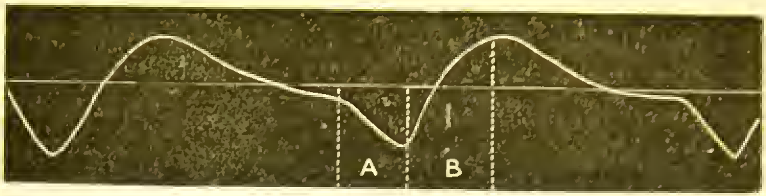

FIG. 27.—Secondary coil. Vibrator in action (Dr Kellogg).

Fig. 28, from a paper by Dr. Lewis Jones,* on the duration of the discharges of the induction coil, also shows, in another way, the abrupt passage from the make to the break before the completion of the former of the two discharges.

FIG. 28.—"Make" discharges (short lines) and "break" discharges (long lines) of a coil (to be read from left to right).

The extent of this interference of the two waves of current depends upon the character of the contact breaker, and varies in different coils, the more rigid the spring, the more likely it is that the rebound or break will follow too quickly upon the make. The shocks of an induction coil can often be very considerably altered in character by a little adjustment of the contact screw, because changes in its position may alter the play of the spring and so make a difference in the way in which it rebounds after contact.

72. **Practical conclusions.**—The induction coil has been considered at some length in the preceding para-

* *Electrician*, London, July 21st, 1893.

graphs because it is perhaps the most important electrical appliance in common medical use, and because the points which have been discussed are of value as a guide in the choice and in the use of the instrument. Taking everything into consideration, the induction coil to be preferred for medical use should be of the sledge pattern, its contact breaker should work easily and evenly, its spring should not be too rigid, its rate should be capable of variation, and its discharge curve should approximate to that of a sinusoidal wave, each discharge being given time to terminate before the commencement of the next succeeding one. There may be two different secondary coils, or else one which is tapped at several places, so that either a part or the whole of the turns may be utilised at will. With a greater number of turns the rise and fall of the current is more gradual than with a smaller number, and the painful effect or shock is lessened thereby.

When muscle is to be stimulated through the moistened skin a lower electromotive force, a smaller number of turns and a slower rate of contact breaker may be used. When cutaneous sensory effects are desired, a large number of turns, a higher electromotive force, a rapid rate of vibration, and a dry skin, are to be preferred. The very rapid vibrator or singing rheotome has its chief use in producing a local anæsthesia in the part to which it is applied. For applications to mucous membranes the short coil is likely to prove more painful than the long coil, unless used carefully, because the mucous membrane with its low resistance may allow a large current to pass even from a coil whose electromotive force is not high. When the long coil is used its own high self-induction will tend to protect the patient, so that the actual electromotive force

applied to the body will be far below the electromotive force of the apparatus, as measured upon open circuit. The effects of the primary coil approximate very nearly to those of a short wire secondary. It has already been stated that the primary current is unidirectional, not alternating; it is probable that its discharge curve is more abrupt and peaked, and of shorter duration than that of the secondary coil, and this difference will be the more marked if the primary consist only of a comparatively few turns.

There is at present no definite evidence to show that there are any important physiological or therapeutical properties possessed by the primary current, and not possessed by a suitably wound secondary.

73. **Magneto machine.**—A few years ago an apparatus known as a magneto machine was commonly used for medical purposes.

The usual form consisted of a horse-shoe magnet with two soft iron rods wound with coils of fine wire mounted on a spindle to turn in front of the poles of the magnet so that the ends of the rods should be presented alternately to each pole of the magnet as the spindle was made to revolve. The coils were connected in series and the free ends were attached to metallic rings on the spindle so that the induced currents could be led off through springs or brushes rubbing on the rings. The spindle carrying the coils or the "armature" was made to revolve at a high speed by means of a handle and some sort of gearing. Then as the iron rods approached the poles of the magnet an electromotive force in one direction would be induced in the coils, and as they receded from the magnet an electromove force in the opposite direction would be induced, the currents led off to the electrodes would therefore be alternating,

and the electromotive force would depend on the speed of rotation of the spindle. There was generally a moveable soft iron keeper attached to the magnet, by shifting the position of which the number of lines of force free to go through the coils and consequently the electromotive force in the coils for a given speed could be varied.

The above described machine may be looked upon as a very primitive and badly designed form of dynamo, but when the magnetic field in which the armature revolves is given by a permanent magnet it is more usually called a magneto machine, and the term dynamo is applied only to those machines in which the magnetic field is made by an electro-magnet. It would take up too much space and be out of place to give an account of any of the numberless forms of dynamo here. We must therefore be content to refer the student to such works as S. P. Thompson's *Dynamo Electric Machinery*, in which a full account will be found of all the chief types of dynamo that are now in use.

Recently the magneto machine has been revived, and in an improved form, has been utilised for medical purposes.

The interest now taken in treatment by the sinusoidal currents of the street mains may give rise to a demand for small dynamo or magneto machines, for producing these currents in places where the electric lighting mains are not available for the purpose, and by modifications in the construction of the armature, sinusoidal currents can be obtained from such machines without any trouble, especially when power is available for setting them in motion. Thus the machine may be driven by a water motor or a hot air motor,* or by an electromotor connected to a battery or to the mains, in

* Norris and Henty, Abchurch Chambers, Abchurch Yard, E.C.

which latter case the apparatus affords a means of converting continuous into alternating current, with the advantage that the rates of alternation can be varied to suit special requirements by varying the speed of rotation of the machine, an advantage which cannot be had with the alternating supply from the street mains, the period of which is maintained, so far as possible, at an uniform figure.

D'Arsonval in Paris has contrived a small magneto machine for giving sinusoidal currents, which is described in the *Revue Internationale d'électrothérapie*,* and has been used by him in the investigations which he there relates. Judging from the figure the instrument does not appear likely to have a very high electrical efficiency, but it does seem to answer admirably for the production of currents alternating with evenness and regularity. Those who are interested in the production of sinusoidal currents by means of small machines should consult the paper just quoted, as also the current and back numbers of the same publication, and of *Arch. d'Electricité Médicale.*

74. **Electric lighting currents.**—During the time which has elapsed since the publication of the first edition of this book, great progress has been made with electric lighting in Great Britain. In London the number of houses connected up to the mains of the different supply companies is very much greater than it was three years ago, and there has been a corresponding increase in the use made of the mains for medical and surgical purposes. Many medical men now use the mains in the treatment of their patients, and more will do so as the safety and convenience of the method becomes better known.

* Paris, April, 1893.

The current supplied by the companies* is in some cases a continuous, and in others an alternating current, the pressure is usually 100 volts. On the former system the current from the mains can be used to charge accumulator cells, these being subsequently applied to the purposes of treatment, or the current can be used direct, its pressure being regulated by means of resistances to suit the different requirements as they arise. Either method can be adopted; the former has the advantage that the energy can be stored in the accumulators, and then can be conveyed to a patient's house, or to any place where it may be wanted; the latter has the advantage that when once the apparatus is fixed up in a proper manner, the supply is immediately available on turning a switch, and there are no accumulators to be attended to. In the matter of cost there is no very great difference between the two plans.

If the method of charging accumulators from the mains be adopted the apparatus required will be as follows:—(*a*) For cautery purposes a two cell accumulator capable of giving fifteen ampères; (*b*) for surgical lamps a four or five cell battery capable of giving 1 to 1·5 ampères, each of these will require a rheostat; (*c*) for medical applications a twenty cell battery, with collector, reverser, galvanometer, and coil, fitted with small accumulator cells instead of primary cells (fig. 17, p. 76).

One battery might easily be contrived to fulfil the requirements of both *a* and *b*, and the Lithanode and

* The St. James and Pall Mall, Westminster, Kensington and Knightsbridge, Chelsea, Charing Cross and Strand, and St. Pancras Companies, supply a continuous current. The Metropolitan, the London, City of London, and House to House Companies, supply an alternating current.

General Electric Company* are now engaged in perfecting such an arrangement.

To charge any of these batteries from the mains is a very simple matter, and the figure shows the method; the current passes in the direction of the arrows from the main, through a plug inserted in the wall socket, to the battery to be charged, and returns through an in-

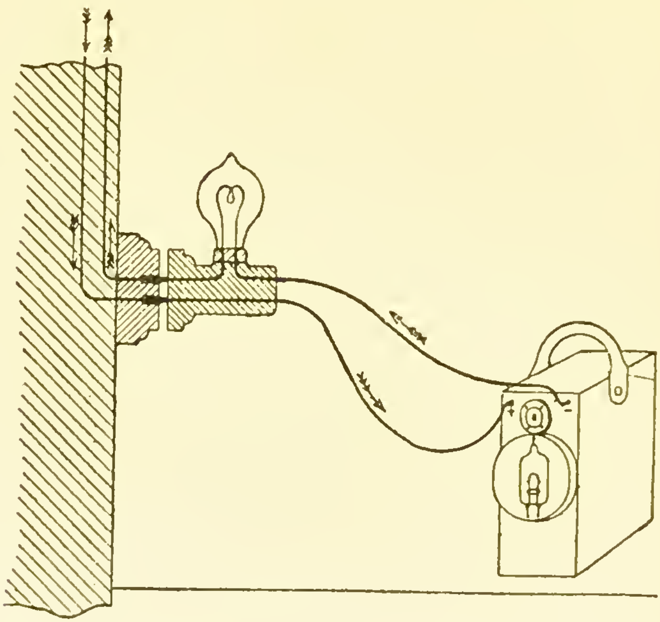

FIG. 29.—Charging an accumulator from the electric light mains.

candescent lamp to the opposite main; the incandescent lamp acts as a resistance and protects the battery from the full pressure of the supply, it also determines the rate at which the battery is charged. By using an 8, 16, 32 or 50 candle power lamp, the rate of charging is completely under control, and the amount of charge

* 64 Millbank Street, Westminster, S.W.

depends upon the length of time the current is left on. A plug fitted with a lamp socket and connecting wires, as shown in the figure, can be had from the Lithanode Company, and can be made to fit any form of wall socket, or lamp socket. The best fitting, however, is that of a concentric plug, for then there is no need to test the polarity of the wires every time the plug is used, as the attachment to the mains can only be made in one direction.

The fullest instructions as to all the details of charging accumulators from the mains will be found in Part 3 of Mr. Niblett's book of *Portative Electricity*,* which should be consulted by everyone who is about to perform the operation for the first time, tables are there given of the rate and time of charging for any number of cells up to forty, through incandescent lamps of the various candle powers in common use.

If the continuous supply is to be used direct, without the intervention of secondary cells, it is very important to have a well made and well fitted installation, so contrived as to make it impossible to apply the full pressure of the mains to the patient. It is not likely, under ordinary circumstances, that a fatal accident would be the result of the direct application to a patient of the full pressure of the mains at 100 volts; but the shock, to say the least of it, would be very severe and its effects might be alarming.

A resistance of 400,000 ohms, which could be reduced gradually to 4000 ohms, would give a range of current through the body from about ·25 of a milliampère to twenty milliampères, and would suffice for most cases. A good way of disposing the resistances would be to

* *A Popular Treatise on Portative Electricity*, by J. T. Niblett, Biggs and Co., Salisbury Court, London, E.C.

divide the rheostat into two parts, the first part going up to 4000 ohms, and the second continuing the resistance to the 400,000 ohms ; the first portion would then require to be touched only very seldom, and could be kept in circuit at its full value of 4000 ohms as a permanent safety resistance, the regulation of current in ordinary cases being made only in the second half of the rheostat.

The safety arrangements should be of such a kind as to make it difficult for the operator to make any mistake through forgetfulness or inattention. It is customary to have an eight candle lamp permanently fixed in the circuit in addition to the adjustable resistances, and with this in circuit the greatest current passing will not exceed 300 milliampères, even if the conducting wires or electrodes should come into accidental contact when all the adjustable resistances are out, this serves to protect the galvanometer and other apparatus from injury. In treating patients from the mains special care must be used, to commence with a very small current, half a milliampère or less, to increase the current very gradually, and to moisten the skin very thoroughly.

For small incandescent lamp instruments an adjustable resistance, going up to 200 ohms or so, will suffice to keep down the current to its proper limits.

For heating cauteries from the mains a properly designed apparatus is necessary. It is a safe rule never to use a cautery on the mains without some special precautions against the formation of an arc at the point of the cautery, for such an accident might be extremely serious.

A description of an apparatus for heating cauteries with safety from the continuous current mains will be found below in the chapter dealing with the galvano-cautery.

75. **Transformers.**—On the alternate current supply mains it is not possible to charge accumulators, but by the use of a simple apparatus known as a transformer the voltage can be regulated with great nicety to suit any requirements of practice. A transformer may be

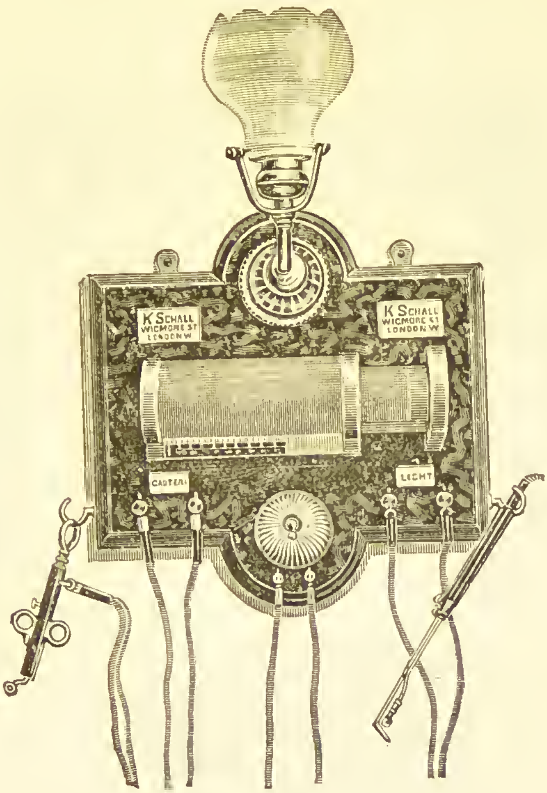

Fig. 30.—Woakes' transformer.

compared to an induction coil, for in both there is an iron core wound with two separate coils of wire, so that a varying current circulating in one coil sets up a similarly varying induced electromotive force in the other, which may be called the secondary coil. By a proper proportion between the turns of wire in the two coils

any desired electromotive force may be had at the terminals of the secondary. As the current supplying the transformer is alternating, there is no need for an automatic contact-breaker like that of an induction coil.

The best known type of medical transformer is Woakes' transformer, fig. 30 (K. Schall). This instrument has three separate secondary coils wound

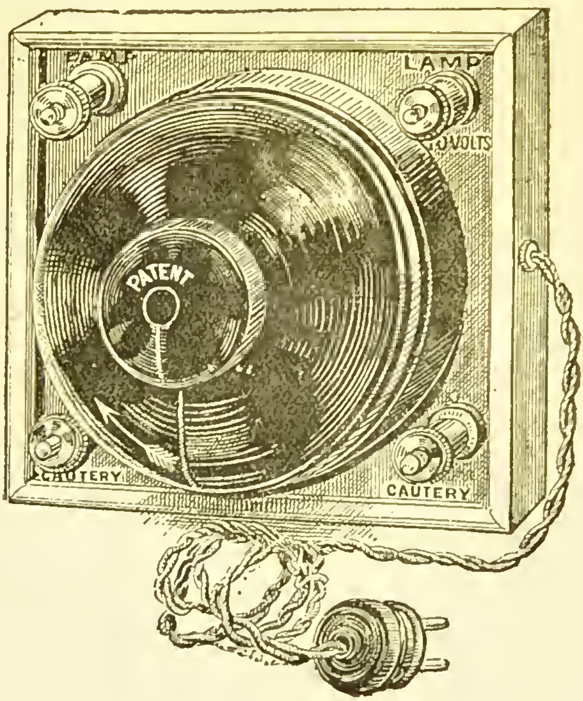

FIG. 31.—Transformer.

upon one bobbin ; one for cautery purposes, one for incandescent lamps, and one for the application of the current to patients. Each has its own pair of terminals. Regulation is effected as in the sledge form of induction coil, see page 93.

Another useful instrument is made by Messrs. Miller and Woods, for use with cauteries and lamps, fig. 31,

and the same firm also have a transformer provided with a number of binding screws, by means of which any voltage, from one volt to one hundred, can be obtained at will. For experimental work this is a very useful instrument, and it may be used in the treatment of patients, fig. 32.

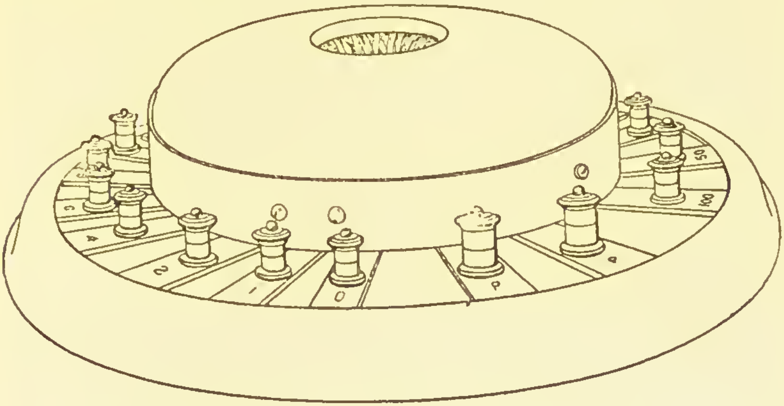

FIG. 32.—Graduated transformer.

Fig. 33 illustrates another type of transformer, which

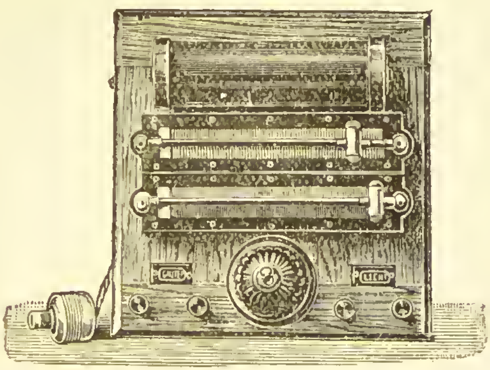

FIG. 33.—Simple transformer for lamps and cauteries.

is simple, cheap and efficient, the current is regulated by the sliding resistances (K. Schall).

The customary voltage for the galvano-cautery is four volts, for small incandescent lamps four to ten volts; for the electric bath about eight volts, and for application to patients twelve or fifteen volts.

The alternating current applied to muscles and nerves produces effects comparable to those of the induction coil, but the rate of alternation is high, varying from 85 periods a second to 120 on the mains of the different London companies. Electrolytic effects, and the effects of steady currents, cannot be had from the alternate supply, though both can be had from the continuous current mains, but these on the other hand cannot give a current to take the place of the induction coil current, but can be used to work a medical coil.

Thus neither the continuous nor the alternating supply can meet all the requirements of electrical treatment directly, though either of them can be made very useful. The most independent position is undoubtedly to have a continuous supply at command, and from that to charge proper batteries of secondary cells, which can be made to supply all the needs of medical practice as well or better than any primary batteries, and with less trouble in the management.

CHAPTER IV.

Accessory Apparatus.

Conducting wires. Binding screws. Electrodes. Current collectors. Commutators. Regulation of current. Resistances. Galvanometers. Voltmeters. The voltameter.

76. **Conducting wires.**—The conductors or leads by which the current is conveyed from the battery or other generator to the place where it is to be used, should be of flexible stranded copper cord. Copper is used because it is the best conductor among metals with the exception of silver, which indeed is not very much better and is out of the question on account of its cost. It is best to use insulated wire and so avoid any risk of shocks or short circuiting from the wires coming into accidental contact with one another. Suitable wires may be bought insulated either with cotton or silk or india rubber, and for cases where the current has to be conveyed some little distance it may be convenient to use double conductors made of two insulated wires twisted together. In this case it is well to mark the ends, so that there may be no difficulty in recognising the positive and negative wires. A pole-tester, § 66, will prove useful for this purpose. It is useful to have the two conductors covered in two different colours, say red and green, as it makes it more easy to distinguish between them, in tracing their attachments to the battery or to the electrodes. A convenient length is four and a half or five feet. The ends of the

flexible wires should be fitted with some simple terminal piece, for attachment to the binding screws, otherwise they are apt to become frayed out and untidy.

In the majority of cases the size of the wire used is immaterial as the conductivity of copper is so high that a very thin wire will carry a current far larger than is required for purposes of medical treatment without any sign of heating, and the resistance of such wire is infinitesimal compared with the resistance of the body. Even when small lamps are to be lighted, unless very fine wire is used, the size is unimportant. But for the large currents that are necessary to heat cauteries, the matter takes a very different aspect. We have seen a thin copper wire, improperly used for connecting an accumulator with a cautery, grow so hot as to melt off the gutta-percha insulation throughout its whole length, while the resistance of the circuit was so increased by the use of this unsuitable lead that the cautery was not heated, although had a proper lead been used the battery power would have been sufficient.

This is an extreme case and only likely to occur with large cautery burners which need a very large current to heat them, but it affords an useful example of the need of attending to the conducting wires.

77. **Binding screws.**—The current is taken from the battery terminals or poles. These usually have binding screws by means of which the leading wires are attached. Binding screws are also used to connect the conducting wires to the instrument to which the current is to be led. It is of the highest importance that at all the points where connection has to be made it should be thoroughly and well done. All binding screws must be kept scrupulously clean, and the larger bearing surface they have the better; the ends of all

wires must also be freshly scraped when connection is to be made, so that there may be true metallic contact at every point of the circuit. A thin film of dirt or metallic oxide at a connection introduces an incredibly high resistance into the circuit. Faulty connections are one of the commonest causes which throw electrical apparatus apparently out of gear, and although it is not hard to detect the fault by careful examination, yet only too often much difficulty is found, and in consequence the battery is condemned, or the services of the instrument maker are called in. It need not be said that this is the wrong way of doing things, for everyone using a battery should make himself familiar with the proper management of it, in order to avoid the expense and annoyance of perpetually putting it into the hands of an instrument maker.

The most perfect metallic connection is made by soldering the wires to the terminals of the batteries or instruments to be used, but this is impracticable in most cases, since it makes it very troublesome to dismount the battery, and in general more than one set of instruments has to be worked from one battery. As a matter of fact with moderate care no difficulty need occur from faulty contacts in binding screws. It is advisable for the sake of neatness, to use but one form of binding screw as far as possible. There are of course many forms in constant use, and a few minutes may be well spent in inspecting an electrical instrument maker's stock.

78. **Electrodes.**—The terminals by which the current is applied to the place where it is to be used are called electrodes. The word electrode is also used to describe the terminals by which the current leaves the battery or enters any instrument. The special ter-

minals used in medical treatment are sometimes called rheophores, a term which has also been applied to the conducting wires, and here we may once for all protest against the use of so many unnecessary terms. Such words as rheophores for electrodes or conducting wires,

Fig. 34.—Carbon disc electrodes.

rheostats or rheochords for resistances or resistance coils, rheotropes for commutators, and rheotomes for contact breakers, are, as a rule, not wanted, and the words in common use among electricians are enough for all medical purposes. The variety in nature and

Fig. 35.—Handle for electrode, with key.

shape of the electrodes used in medical practice is immense; it is necessary, however, to describe some of them. The old fashioned brass handles and wet sponges are now almost wholly abandoned, and the favourite form of electrode at present is a disc of carbon or of nickel plated metal screwed into an insulating (wooden) handle and covered over with wash-leather or amadou.

The handles are of varied design, some being fitted with keys for closing the current or for opening it, or even for reversing it, one or two of these handles are figured here, and many more will be found in the instrument makers' catalogues. One handle with a key for *closing* the circuit is useful for the testing of muscles.

The greatest care must be exercised to prevent risk of communicating contagion through the medium of the electrodes, on this account metal is better than carbon; the amadou, or flannel, or wash leather covers, should be often renewed, and as far as possible a separate set should be kept for each patient.

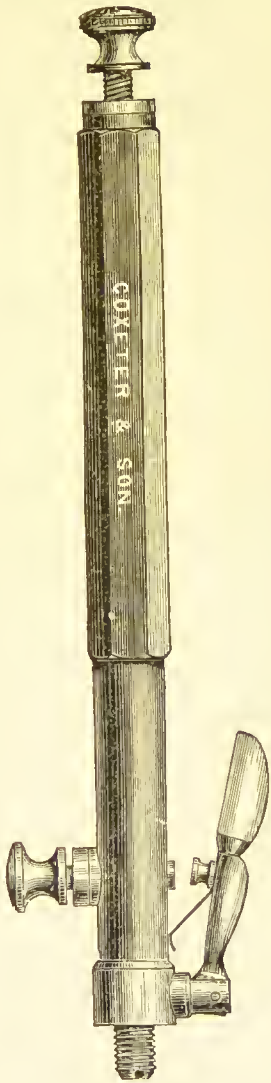

FIG. 36.—Handle for electrode with key for making and breaking circuit.

Several sizes are required. Professor Erb has suggested the adoption of electrodes of standard sizes because the density of the current and the effective resistance of the surface at the point of entry depends upon the size of the electrode, that is to say, the area from which the current passes to the patient. For different effects one may desire at one time a current diffused over a large surface of entry, and at another a current concentrated at a small surface. In the operation for the removal of superfluous hairs by electrolysis, the indifferent electrode is large and the local effects on that part of the skin which it touches are imperceptible,

but the active electrode is a fine platinum needle, and the density of the current at its point is such that strong local effects are produced where it pierces the skin even when the current is only three or four milliampères. By using standard sizes too one can more readily convey to others a correct idea of the current density used in any particular case. Erb's standard sizes are the following :—

Name.	Diameter of disc.		Area of surface.	
Smallest	·5 cm.	·2 in.	·25 sq. cm.	·04 sq. in.
Small	1·5 ,,	·6 ,,	1·1 ,,	·28 ,,
,,	2 ,,	·8 ,,	3·14 ,,	·5 ,,
Normal	3·5 ,,	1·4 ,,	10 ,,	1·5 ,,
Medium	5 ,,	2 ,,	20 ,,	3 ,,
Large	7·6 ,,	3 ,,	50 ,,	7·6 ,,
Very large	11·2 ,,	4·4 ,,	100 ,,	15 ,,
,,	13·3 ,,	5·25 ,,	150 ,,	23 ,,

These sizes do not cover all the variations which are required for medical practice, for in Apostoli's treatment of uterine disease the indifferent electrode is larger still, while, for nævi and epilation, electrodes made of fine sharp needles are used. An obvious objection to this series of sizes is that they are not very regular in scale, and that for the important size of "small" electrode two alternatives are proposed. Moreover, the numbers are difficult to remember; it would be quite as useful and more convenient to adopt a series of circular electrodes numbered according to their diameter in centimetres from 1 to 10. Still another size is proposed by the same author (Erb) for use in testing the contractility of muscles, namely one of 4 cm. diameter.

For practical purposes of diagnosis and treatment it will generally suffice to have three or four sizes of disc electrode, the smallest of half an inch or one centimetre in diameter, the largest of two inches (five centimetres), these, with one or two roller electrodes, fig. 37, and a fine wire brush electrode, will answer very well for almost all purposes.

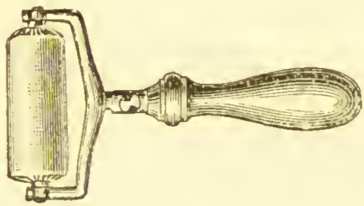

FIG. 37.—Roller electrode.

A very good form of disc electrode is made, in which the operation of renewing the wash leather covering can be quickly carried out without needle and thread. The electrode is made of two cupped discs of metal, which screw together, and so hold the edges of the wash leather firmly fixed between them.

The more special forms of electrode will be described and figured in the chapters which deal with the particular operations in which they are used.

In some medical applications both the poles of the battery are used equally, and in that case the electrodes at the two poles may be similar, but more often the current is applied to the affected part with one pole, which is then known as the "active electrode," and may be positive or negative according to the treatment required, the circuit being completed by the application of the other electrode, the "indifferent electrode," to some convenient part of the body; under these circumstances the active electrode may require a handle for its proper

manipulation, while the indifferent electrode is most conveniently arranged as a simple metal plate, which can be applied to the surface of the body and left there during the treatment. It is generally an oval plate of pure tin or pewter four or five inches long. It is light and sufficiently flexible, and can be bent to fit the surface of the body. Plates of lead are not so good, nor so

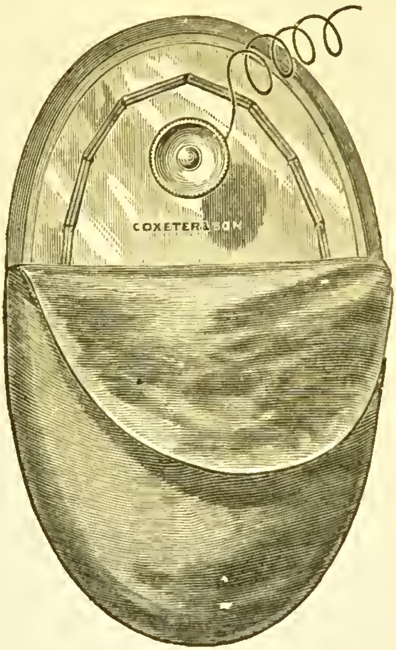

Fig. 38.—Tin electrode and sheath.

convenient. On one side is a binding screw for the attachment of the battery wire, and the other side is covered with a smooth piece of amadou or wash leather, which can be moistened with warm water before use. There should be a sheath or pocket with one side waterproof, to contain the electrode (fig. 38), this will serve to protect the patient's clothes from being wetted with-

out interfering with the passage of the current. Bare metal must never be applied directly to the skin unless electrolytic effects are wished for, the current is very much more painful when it enters the skin from a metallic surface than when it first passes through a layer of moist badly conducting material. The reason for this is that the latter gives a more even contact, and most of the electrolytic action takes place in the thickness of the wet flannel or washleather instead of in the skin.

The indifferent electrode may be slipped between the clothing and the skin, the pressure of the clothes will then suffice to keep it in place, or if the patient is lying down the electrode may be put underneath the shoulders or the hips, or it may be held against the body by the patient himself or by an attendant. In either case the operator is able to give his whole attention to the other or active electrode. Care must be taken to see that the contact of the indifferent electrode with the skin is well maintained, and that no dry clothing lies between. Sometimes, especially with children, it may be fastened on by a few turns of a bandage, or by a soft garter or belt of some kind. Electrodes to buckle or clasp upon a limb are figured in the catalogues and are useful. The precaution should be taken of seeing that the proper side of the sheath and the proper face of the electrode are together, for the waterproof side will not conduct.

79. **Current collectors.**—Medical batteries for galvanic treatment are made up of a large number of cells (20, 30 or 40 arranged in series), but the number of cells to be used for different cases varies very much. On this account a quick and simple plan of altering the number of the cells included in the circuit is required so

that the current may be readily increased or diminished to suit the needs of each case by switching cells in or out of circuit. The plan is as follows:—

In the diagram, fig. 39, six cells are shown numbered I to VI, they are joined in series, and from their terminals wires are led off to seven corresponding studs numbered 0 to 6. It may be seen that a moveable metallic arm springing on to stud No. 1 will throw one cell into circuit between the binding screws marked + and –, and similarly when the arm is placed on any other stud it brings into the circuit the number of cells shown by the figure marked against the stud.

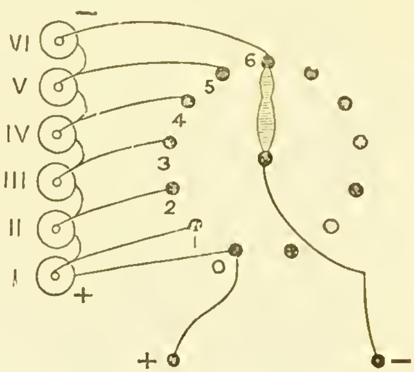

FIG. 39.—Plan of single current collector.

This is in brief the principle of the current collector, as applied to medical batteries, the stud marked 0 being connected with one pole, say the positive pole of cell No. 1, and leading to a binding screw marked +, stud No. 1 being attached to the negative pole of the same cell and when the moveable arm touches stud No. 1, the current passes along it and from there goes to the other binding screw of the battery marked as shown in the figure. Cell No. I. only is then included in the

circuit; if the pointer be transferred to another stud, numbered let us say 6, then six cells are in circuit and are being used.

A more complicated current collector has been devised, by means of which the current may be taken from any cell or any group of cells commencing at any point, the advantage being that the cells can be used equally, so that the wear and tear is more evenly distributed. In the single collector the first cells are always drawn upon, and are likely to run down before the last cells, which are only needed occasionally. With the double collector, if six cells are required, not only could cells 1 to 6 be chosen, but cells 4 to 9, or 7 to 12, or 13 to 18, or any other set of 6. With the single collector the first cells must always provide current and cell No. 12 can only be used when eleven cells are insufficient. Accordingly, with a single collector, the last cells of the series are very seldom called on at all, while the first cells have to do duty every time the battery is used. Another advantage of the double collector is that with its aid the working of every cell of the battery can be separately tested; the double collector, however, is rather more expensive. If in the figure of the single collector (fig. 39) the wire leading from cell No. I. to the stud numbered 0 were not continued to the positive terminal of the battery, and if this latter were connected instead to a second arm, pivoted on the same axle, but electrically insulated from the first one and capable of independent movement (fig. 40), it can be seen that with the two arms on the studs 3 and 6 the current would be taken from cells IV., V., and VI. only, that is to say the group of cells IV. to VI. would supply the current to the circuit. In like manner any number of consecutive cells from one upwards could be

picked out from any part of the whole series. It is usual for one of the arms to carry a circle so divided and numbered as to read off directly the number of cells in use (fig. 40).

The studs of current collectors must be of good size, and the pointer just broad enough to touch two at once, that the number of cells in the circuit may be increased or diminished without breaks of current and unpleasant shocks at the moment when the pointer moves from one

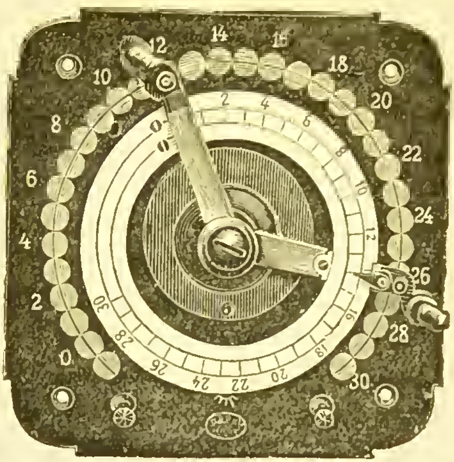

Fig. 40.—Double collector.

stud to the next. At the same time care must be taken that the moveable pointer of any collector is not left for any length of time in contact with two studs at once, for when it is in that position one cell is short-circuited and its energy is being ruinously wasted.*

When it is wished to test the working of a medical battery, the poles must be joined through a high re-

* This can be prevented by the use of a collector having a divided arm, with its two portions joined through a resistance of fifty ohms or so, see fig. 20.

sistance, for example, any of those described in § 82. With about 1000 ohms the current is reduced to a magnitude suitable for measurement with the milliampère meter; failing this the electrodes should be placed in a saucer of water, some little distance intervening between them, and the pointer must then be gradually moved round the studs, the galvanometer being watched carefully. If the battery is in proper order it will indicate a regular rise of current step by step, for every cell added to the circuit. If the galvanometer needle falls to zero as the pointer is passing from one stud to the next, it indicates that the current is broken at that moment, and if a patient were in circuit he would receive an objectionable shock. If the needle falls to zero when the pointer is on a stud, it shows that the connexion between that stud and the battery is faulty. See also § 86.

It is a bad practice to try to test a battery by connecting the terminals by a direct metallic contact except through a coil of high resistance, 1000 ohms or so, otherwise the strength of current may be so great as to damage the galvanometer, and it will probably be too large even with one cell for a galvanometer graduated in milliampères to give readings of it. If no resistance coil be at hand the plan of putting the electrodes into a saucer with a little water will usually suffice to reduce the current in the circuit to a quantity which can be measured in milliampères.

80. **Commutator or current reverser.**—An apparatus for reversing the direction of the current in the external portion of the circuit is indispensable for some medical purposes. It is difficult to make a satisfactory examination of the reactions of nerve and muscle without one. There are several forms in common use, but

one only will be described, as it appears to be the most convenient in medical work. This pattern is shown in the accompanying figure (fig. 41); it was devised by Rhumkorff.

It consists of a cylinder of vulcanite M, having at each end a metal cap or ferrule C, D, and supported between two uprights in such a way as to revolve easily about a horizontal line, each end is connected to a binding screw A, B, and each metal cap is prolonged in the form of a cheek E, F, along one side of the vulcanite cylinder for two-thirds of its length. On either

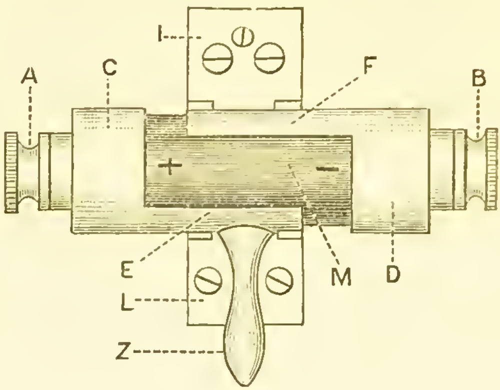

FIG. 41.—Commutator.

side of the cylinder springing against it, are two pieces of metal I, and L, connected with the terminals of the battery. When the cylinder is turned by means of the handle *Z*, either of the metal cheeks can be brought into contact with each of the springs I, L. The positive pole of the battery connected say with L, can thus be brought into connection with either the binding screw at A, or at B, so that the current can be made to pass in either direction at will round the external portion of the circuit between A and B. The + and −

signs on the vulcanite cylinder indicate the polarity of the binding screws; in the position shown A is positive, a half revolution of the cylinder alters A to negative, and therefore the reverse side of the cylinder which then comes into view will have the + and – signs transposed also.

81. **Regulation of current.**—When the current is regulated by the method described in § 79, it will be seen that, neglecting the resistance of the battery, the electromotive force is the only thing altered in the circuit. But by Ohm's law we know that the current is numerically equal to the electromotive force divided by the resistance of the circuit, so that it might be regulated by introducing or removing resistances, the electromotive force being kept constant. In some cases it is more convenient to regulate by this method. As for example, in regulating the current from the electric light mains, where the electromotive force is maintained at a constant figure. In general, with batteries, when the total resistance of a circuit is large, it is more convenient to alter the electromotive force than the resistance in the circuit. Thus, suppose a circuit has a total resistance of 3000 ohms, and is acted on by twelve cells of 1·5 volts each, there will be a current of six milliampères; if now it is required to double the current it is easily done by adding twelve more cells, taking for granted that their internal resistance may be neglected, but if it were desired to make the alteration by reducing the resistance of the circuit it would be necessary in order to double the current, to take out a resistance of 1500 ohms, which might be impracticable. When it is desired to increase current by taking out resistances, it is of course requisite that the resistances to be removed must first be connected up in the circuit

before the commencement of the operation. If the total resistance is small this can be done, and in such cases the current is most easily governed by variable resistances in the circuit. Thus, suppose a circuit made up of a cautery burner whose resistance with its leads amounts to ·01 ohm, and an accumulator whose electromotive force is two volts and internal resistance ·002 ohm; the current would be well governed by having a variable resistance up to ·5 ohm in the circuit. When the current was turned on with full resistance it would amount to about 3·9 ampères, and by reducing the variable resistance to ·098 ohm a current of 20 ampères would be given which would probably suffice to heat the burner.

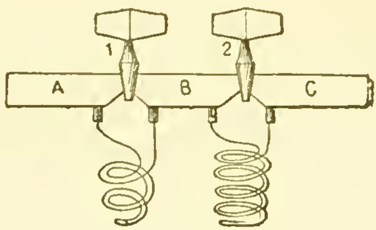

FIG. 42.—Plan of resistance coils.

82. **Resistances.**—Resistances or rheostats* are made up in many forms to suit the purposes for which they are required, and the currents they have to carry. Fig. 43 shows an arrangement of standard coils for measuring purposes, to form a "resistance box." The coils are generally made of a length of insulated German silver wire doubled on itself, fig. 42 (that the coils should have no self induction) and coiled

* The word "rheostat" is perhaps the least objectionable of those referred to in § 78, solely, however, because it has been hallowed by use.

on a bobbin. Coils are then arranged in the following order:—1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1000, 2000, 2000, 5000 ohms respectively, so that any of them can be thrown in or out of circuit by removing or replacing plugs on the top of the resistance box. It will be seen that with the above arrangement of coils any resistance from 1 to 10,000 ohms can be put into circuit. Such resistance boxes are capable of the very highest accuracy, but as a rule this is not required in medical work, and they are damaged if any large current is sent through them, besides which they are

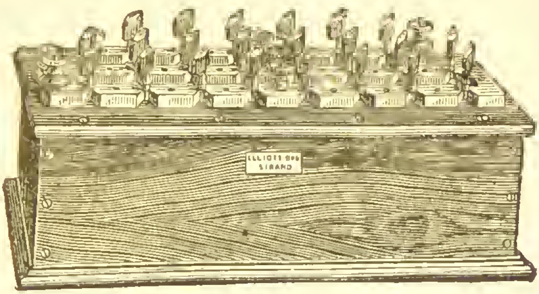

FIG. 43.—Resistance box.

exceedingly costly. They are necessary for scientific investigations, or where it may be necessary to find resistances of apparatus or the electromotive force of batteries with high accuracy.

For medical purposes it is more important to have a resistance which can be smoothly adjusted and varied while the current is passing, than to know the exact resistance in ohms.

An useful form of adjustable resistance is shown in figure 44, where a moveable arm is made to touch successively upon a series of metal studs, the amount of resistance thereby interposed being shown by figures marked opposite the studs.

A form of resistance coil that will frequently be found useful is sometimes known as the "wire rheostat." It is very convenient in cases such as the example given above, in which there is a small external resistance only in the circuit, and a large current is to be regulated. It usually consists of a long open corkscrew coil or helix of moderately thick uncovered German silver or other wire, such as platinum-silver alloy, of high specific resistance. The current is led in at one end of the helix

FIG. 44.—Adjustable resistance.

and a metal sliding piece which can pass from end to end of the coil forms the other terminal. The resistance interposed is easily seen to be proportional to the number of turns of the helix between the end attached to the terminal and the sliding piece. The form of this resistance is favourable to cooling, thus a much larger current may be driven through it than through a coil of covered wire not open to the air. It is especially useful for regulating the current in cautery or lamp instruments. Two resistance coils of this type are shown in fig. 33, and a similar resistance coil of circular form is used to regulate the battery, fig. 16.

83. **Water rheostat.**—Another adjustable resistance apparatus is the "liquid rheostat." It consists of a glass cylinder, watertight and filled with water or some saline solution, it terminates below in a metal foot B and binding screw, and a metallic rod having a screw passes in from above through a collar A, and this carries the other binding screw. When the rod is screwed quite down it touches the base of the tube, and the circuit is

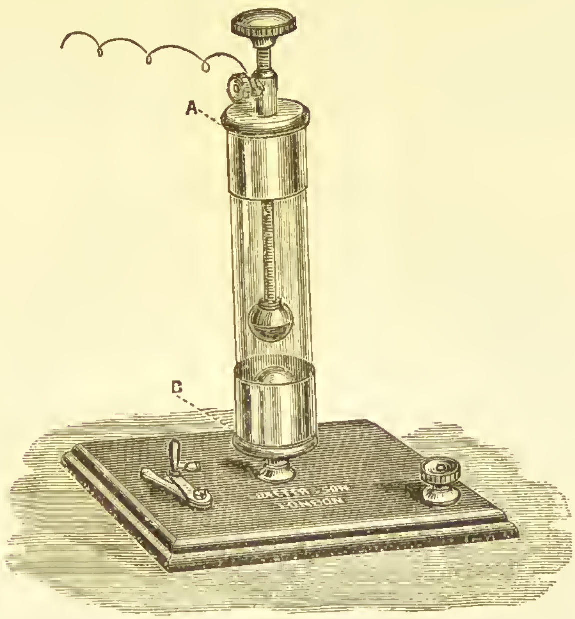

FIG. 45.—Water rheostat.

completed through the metallic contact; when it is raised the current must pass through the badly conducting liquid. The resistance offered by the liquid varies with the length of liquid to be traversed and the nature of the solution, and the rod can be roughly graduated for the resistance of the liquid to be used. In a modification of this instrument a damp sponge takes the place

of the liquid; the resistance varies with the pressure upon the sponge, which is regulated by turning a screw, as before.

84. **Graphite rheostat.**—A very handy form of adjustable rheostat for high resistances and small currents is a sliding graphite resistance, figs. 46 and 47. It consists

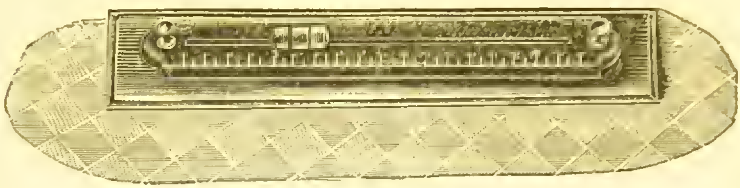

FIG. 46—Graphite rheostat.

of two parallel pencils of graphite, with a metal sliding piece moving between them, and in contact with both. As the position of the slide is altered, a greater or less length of the badly conducting graphite is brought into the circuit, and the resistance of the circuit is varied.

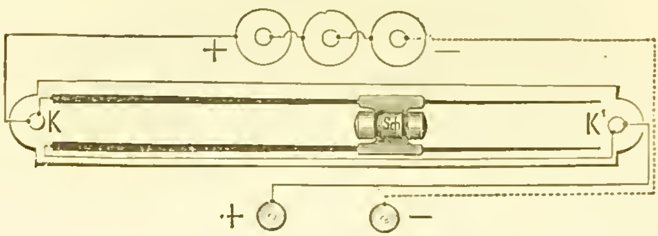

FIG. 47.—Plan of graphite rheostat.

It must be borne in mind that a resistance, suitable for regulating small currents, may be burnt and destroyed if large currents are allowed to traverse it, also that a resistance of one or two ohms may be ample for regulating a lamp or cautery, but will exercise no ap-

preciable regulating effect upon a circuit of high resistance. In general a rheostat should have a resistance approximately equal to that of the circuit which it is to control.

85. **Galvanometers.**—It is generally of the utmost importance that the medical man shall be able during the course of an electrical operation to see at a glance what current is passing, and for this purpose a galvanometer is necessary. We may refer the student back to § 31 for a cursory account of the theory of the galvanometer. Here we have to describe one or two that are in common use.

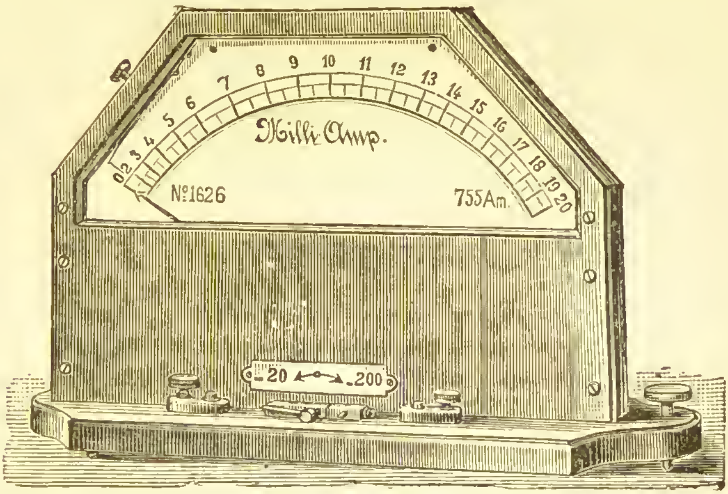

FIG. 48.—Vertical galvanometer.

Galvanometers for medical use are invariably calibrated and marked to read in milliampères by the makers.

A galvanometer calibrated to read milliampères may be called a "milliampèremeter" just as one calibrated to read ampères is called an ammeter. Medical men

owe it to Dr. De Watteville that the milliampère has been chosen to be the standard for medical purposes, and for this it is a most convenient measure.

Medical galvanometers may be conveniently divided into the vertical and horizontal forms. Fig. 48 shews one of the vertical type. They are easy to read, but after a time they cease to give correct readings and indicate too low a figure. They are convenient in use,

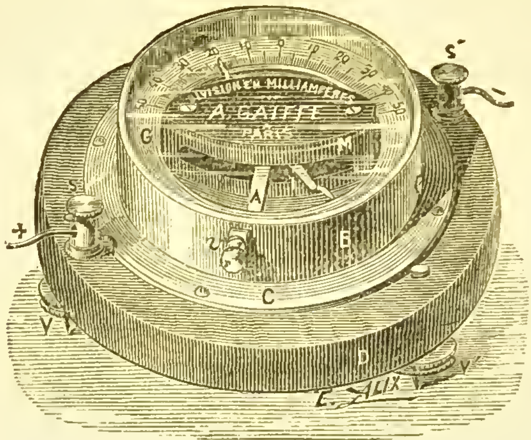

FIG. 49.—Horizontal galvanometer.

however, because it is not necessary to set them in a definite position with regard to the north and south line (magnetic meridian) at the place where they are to be used.

Fig. 49 shews a horizontal galvanometer of a form made by Gaiffe, of Paris, and also explains the construction of the instrument. S S′ are binding screws, V V′ are levelling screws, D the base board, G the graduated scale enclosing the wire coils, B and C the metal case of the instrument. The small screw at *v* moves the lever A, which lifts the needle off its pivot

when not in use. The pointer is made of aluminium for lightness sake, and is set at right angles to the real magnetic needle which is hidden inside the coils.

Before use the instrument must be so placed and

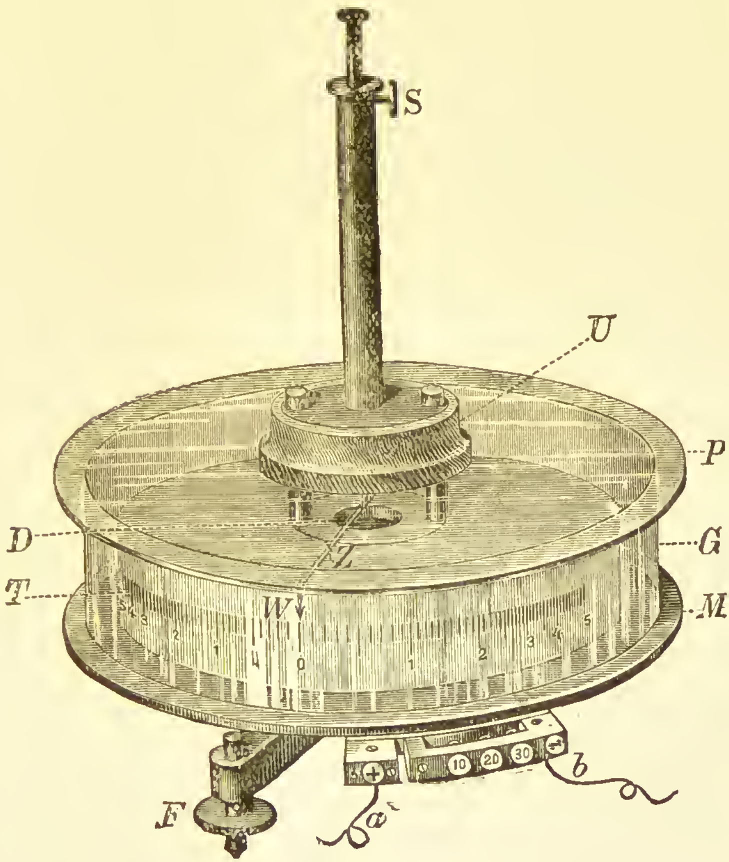

FIG. 50.—Edelmann's galvanometer.

levelled, that the needle comes to rest at the zero, and swings freely about that point. The magnetic needle then points along the magnetic meridian of the place where it is to be used.

This instrument can be made to measure either small or large currents as desired.

Fig. 50 is a representation of Edelmann's large non-portable galvanometer which is a very convenient and beautiful instument. At F is seen one of the three feet of the instrument with its levelling screw, M is the base board, G a short cylinder of glass covered by a glass top, P, which is perforated at the centre for the needle suspension to pass through ; these make a case for the instrument and keep it from dust. The magnet with its long straw pointer Z, the end of which is seen at W, is suspended by a cocoon silk fibre supported from a pin, which can be raised and lowered by a rack and pinion worked by the milled head, S. U is a wooden ring which supports the pillar down which the suspension passes. T is the scale, a cylinder of paper divided to read in milliampères. This arrangement of the scale is specially designed in order that the instrument may be read from a distance. At *a* and *b* are seen the wires which lead the current into and out of the galvanometer, the three small discs numbered in the figure 10, 20 and 30, should be numbered 10, 100, 1000, they are the heads of three screws by means of which shunts can be thrown in to reduce the proportion of current passing through the galvanometer to $\frac{1}{10}$, $\frac{1}{100}$ or $\frac{1}{1000}$, respectively of that in the whole circuit, so that when one of these is in use the reading of the scale must be multiplied by 10, 100 or 1000, as the case may be, to give the whole current in the circuit. In this way the instrument is enabled to give readings over a much wider range than would otherwise be possible.

The arrangement of the shunt circuits is illustrated in fig. 51. Between the binding screws marked + and – the galvanometer coils are represented. Two other paths

are shown beneath, either of which can be completed at the points of their respective screws; both of them have a lower resistance than the circuit of the galvanometer coils, and when closed they convey nine-tenths and ninty-nine hundredths respectively of the current, while the remaining tenth part or hundredth part traverses the galvanometer coils and produces its proper deflection. But if the deflection is known to be due to one-tenth of the current only, then to get the total current the indicated reading must be multiplied by ten, and the same for the other or 100 times shunt.

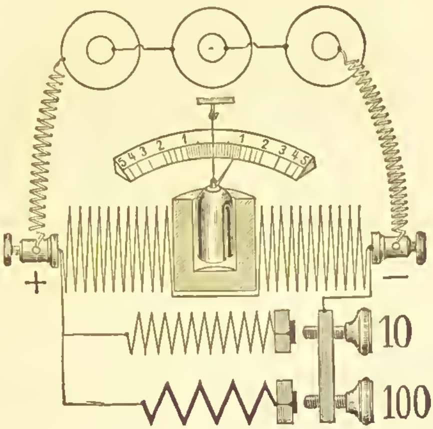

FIG. 51.—Plan of shunt circuits of a galvanometer.

Both shunt circuits are not to be closed at one time.

By means of a battery and a resistance box it is easy to verify the readings of a galvanometer and to determine whether the shunts work properly and correctly. A smaller galvanometer suitable for portable batteries is shown in fig. 52. It has two shunts like the large Edelmann instrument, and its needle is suspended by a silk fibre, and has an arrangement by which the strain

can be taken off the fibre when the instrument is not in use. Suspended needles are very much better than those which are balanced on a pivot, they work with less friction, and give more accurate readings. Galvanometer needles should not be allowed to remain swinging when not in use. If pivoted, the perpetual swinging soon blunts the point of the pivot.

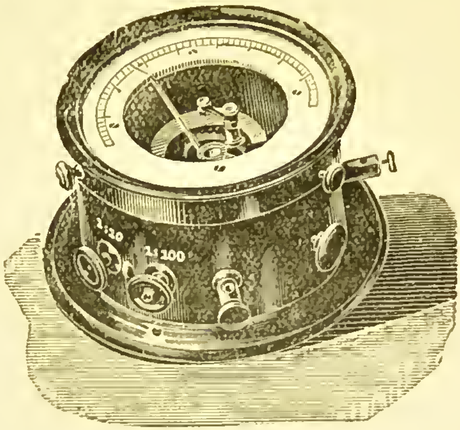

FIG. 52.—Small galvanometer.

In another form of galvanometer, sometimes known as the D'Arsonval type, the movements of the needle are controlled by placing it in a strong magnetic field between the poles of a horse-shoe magnet; this has the effect of making the movement of the needle very "dead beat," that is to say it takes up its position without oscillating to and fro, and so when current is being measured time is saved; on this account they are much in favour for certain purposes, but it is very necessary to recalibrate them from time to time, for the value of their indicated deflections alters as the strength of the controlling magnet diminishes with the lapse of time. This defect tends to make them less suitable for gene-

ral medical practice; but where they are properly attended to they are very convenient.

Vertical galvanometers in which the position of the needle depends partly upon gravity, and partly on the magnetic strength of the needle are also liable to read too low as the needle gradually loses its magnetism.

Horizontal galvanometers of the type figured above, figs. 49, 50, 52, are free from these objections; in these the position which the needle takes up is the resultant of two forces, viz., the attraction of the earth's magnetism tending to hold the needle in the magnetic meridian, and the attraction of the field of force of the coils tending to draw it into a position at right angles to this. Changes in the magnetism of the needle do not alter the relation which the two opposing pulls bear to one another, and therefore the deflections of the needle are not altered if the magnetism of the needle becomes diminished.

86. **Ammeters and Voltmeters.**—Instruments which are calibrated and marked to give readings direct in ampères or in volts are called by the above names. As a rule they have the form of galvanometers, and are specially wound to suit the currents or voltages they are to indicate. In medical practice it is not often required to measure currents of a magnitude of several ampères unless one wishes to know the strength of current needed for lamps or cauteries. In general an ammeter has a very low resistance, and must not be coupled direct to the terminals of an accumulator or to the main supply without some instrument or other resistance in the circuit to protect it from being overheated.

Voltmeters on the other hand generally have a high resistance. The most convenient way of measuring the

electromotive force of a medical battery is to use its own galvanometer, and by a simple calculation from Ohm's law the voltage of the cells can be calculated as follows.

Supposing the resistance of the galvanometer to be 25 ohms, and a resistance coil of 975 ohms be connected to the terminals of the battery ; the total resistance in circuit will be 1000 ohms.

Now one volt acting upon a resistance of one thousand ohms will cause a current of one thousandth of an ampère to flow, that is to say one milliampère. With five volts, five milliampères and so on. The readings of the galvanometer in milliampères will therefore express the electromotive force of the cells in volts if the resistance of the circuit amount to one thousand ohms ; the slight correction for internal resistance of the cells may be disregarded. This method has the advantage of measuring the electromotive force under conditions like those for which the battery is to be used.

Instrument makers supply, if required, a resistance coil properly wound to bring up the total resistance of the galvanometer circuit to a thousand ohms, in order to simplify this mode of measuring the electromotive force of the cells of a medical battery. With this it is very easy to test the voltage of the individual cells by taking readings of the galvanometer while switching on the cells one after another. Each cell may be taken separately if the battery have a double collector § 79, if it have a single collector, the increase of reading for each cell may be taken to represent its electromotive force.

There are many other types of voltmeter for other purposes. Cardew's consists of a long and fine platinum iridium wire which is heated by the current, and ex-

pands, moving a pointer which indicates the expansion on a specially calibrated dial. Ayrton and Perry's is a coil or solenoid, which draws a soft iron core into it, and the movement is indicated on the dial by a very ingenious spring invented by them. The electrostatic voltmeter is an adaptation of the principle of the mutual attraction of oppositely charged bodies. It uses no current, and will read equally well on either continuous or alternating circuits, as also does Cardew's. All these instruments are calibrated by the makers to read in volts, but should be checked from time to time by the user or the maker.

87. **Voltameters.**—The periodical testing of a galvanometer is best carried out by comparing it with a standard instrument or else by means of a voltameter. The latter method is an electrolytic one; and consists in passing a current through the galvanometer and an electrolyte for a measured time; and determining the amount of chemical decomposition which has been produced, § 41, from this the current can be calculated, and compared with the readings given by the galvanometer.

In the water voltameter the products of electrolysis are the gases Oxygen and Hydrogen, and these are collected and measured in some conveniently designed apparatus. Ten milliampères of current will liberate 1·056 cubic centimetres of mixed gases in ten minutes. The electro-deposition of metallic silver or copper from their solutions, may also be used for voltametric purposes. See Ayrton, *Practical Electricity*, Chap. I. and VIII.

88. **Practical note.**—In concluding this short account we would remind the reader that there are few things so difficult to follow in all their vagaries as

the connections of electrical apparatus. Probably at first he will find the greatest difficulty in making the simplest piece of apparatus work. But he need not therefore jump to the conclusion that the battery or galvanometer or instrument that he is using is out of order, and that the instrument maker need be sent for to put it right. The connections should first be examined and in all probability the fault will be found there. It is a very good thing to draw a diagrammatic plan of these and so check them off and make certain that all wires are connected up in the intended way. It is of course understood that the values of the various electromotive forces and resistances in the circuit have been so arranged as to give the required effect. If things will not go right then, the resistances and electromotive forces of the batteries should be taken and it will be quite time enough to apply to the instrument maker when something has been found to be wrong with these. A little intelligence in the application of theory will often save much cost and trouble in practice.

CHAPTER V.

Electricity of High Potential. Statical Electricity.

Historical. Description of instruments. Wimshurst's machine. Conductors and electrodes. The Leyden jar. Modes of application. Treatment by charging. Effects of a positive charge. Treatment by sparks. Treatment by shocks. The brush discharge. Static induction. Effects of electrostatic treatment. High frequency and high potentials. D'Arsonval's experiments.

89. **Introductory.**—In comparing the so-called Electrostatic or Statical methods with other kinds of electrical treatment, it is found that an important feature of the former is, that very high electrical potentials even up to a hundred thousand volts or more are employed.

These enormous voltages can usually be applied to patients without danger, because of the small capacity (§ 22) of the machines commonly employed for producing them. The actual current in the discharge from an electrical machine is very small. Any rise in the capacity of the apparatus is accompanied by an increase in the magnitude of the discharge and in the sensation of shock, thus machines with large prime conductors, or those which have their capacity greatly augmented by Leyden jars (§ 24) may give shocks which are severe or even dangerous.

90. **Historical.**—In the early applications of electricity to medicine the statical apparatus was the only form used because it was the only one known. For many years after the discoveries of Galvani and Volta statical

electricity still remained in exclusive possession of the field of electro-therapeutics. The number of accessories required, the expense and cumbersomeness of the machines, and the unpleasant shocks employed as the chief mode of its administration prevented its frequent use in the treatment of disease, and after a time it fell into disuse, but has been revived again of late years.

As has been mentioned in a former chapter, Jallabert in France (1748) was one of the first to apply statical electricity to medicine. He was followed in 1749 by the Abbé Nollet. In 1745, De Haen in Germany published a number of cases of spasmodic, paralytic and other nervous affections cured by electricity.

In 1758, Benjamin Franklin relates that in consequence of the cures reported to have been made in Italy and Germany, a number of paralytics were brought to him for treatment from various parts of Pennsylvania and the neighbouring provinces.

In 1759, John Wesley, the great divine, collected and published in a book called *The Desideratum*, the details of a vast number of cases treated by electricity. Among them he mentions that electricity accelerates the passages of calculi through the ureters. He also relieved tertian and quartan fevers, and hysteria.

In 1773 and 1778, Manduyt published two works on statical electricity.

In 1777, Cavallo published in London a complete treatise on electricity in theory and practice, with original experiments.

In the next year there appeared the thesis *De Electricitate*,* by Dr. Robert Steavenson of Newcastle, which has been already alluded to.

In 1783, Wilkinson, and a few years later Birch, also

* Reprinted by Messrs. J. and A. Churchill in 1884.

wrote upon the subject. Then follow the reports of cases in the *Guy's Hospital Reports* treated by frictional electricity by Addison (1837), Golding Bird (1841 and 1846) and by Sir William Gull (1852-3); and later by Dr. Radcliffe in the National Epileptic Hospital.

More recently (1873) Dr. Arthuis of Paris has revived the treatment by statical electricity and has published a book on its use in nervous and rheumatic affections. Electrostatic methods have been greatly used by Professor Charcot and by Dr. Vigouroux at the Salpêtrière; and recently attention has been paid to the subject by Dr. McClure in this country, and by Dr. Morton in America.

91. **Description of instruments.**—The first form of electrical machine was a large sulphur ball which was excited by one hand as it was revolved by the other. It was made by Otto von Guericke of Magdeburg in 1672. Some interesting reproductions of old figures of early electrical machines are given by Dr. Mount Bleyer, of New York, in Bigelow's *System of Electro-therapeutics.* Subsequently resin was used and then a glass cylinder instead of the sulphur ball. In 1740 Winckler excited the glass by means of horse-hair cushions covered with silk instead of the hands.

In 1760, Ramsden substituted a circular glass plate for the cylinder, and his apparatus was until recently in common use. In Ramsden's machine electrical separation is produced by the friction of the glass disc between two sets of cushions.

In most modern machines induction is utilized for producing the electrical separation, and on this account they are often known as influence or induction machines. In 1865 Holtz, of Berlin, invented a machine which, when charged from an electrophorus would continue to

produce electrical separation by induction. This form of machine proved to be much more powerful than the best frictional machines. About the same time a similar machine to that of Holtz was invented by Toepler.

Subsequently a self-exciting machine was invented, known as the Voss machine. It is still the favourite in Germany, although in England Wimshurst's machine is preferred. It is somewhat similar to the Holtz and it is said to act well in all weathers. This is not quite correct for the English climate, but still it is less easily affected by the weather than are the frictional or combined frictional and induction machines.

The labour required for revolving the plates is light, but like many of these induction machines it has the objection that the poles are apt to reverse when the electrodes of the machine are separated beyond sparking distance.

92. **The Wimshurst machine.**—The Wimshurst machine is an improvement on the Voss in that it is readily self-exciting, and will work in almost any weather. It is the best machine for medical use as its polarity will not reverse under ordinary circumstances while it is in action. It consists of two circular glass discs (or any even number up to twelve), mounted in pairs upon a fixed horizontal spindle in such a way that they rotate in opposite directions at a distance apart of not more than one-eighth of an inch. Each disc is attached to the end of a hollow boss of wood, or of ebonite, upon which is turned a small pulley. The pulleys are driven by a cord or belt from larger pulleys attached to a spindle below the machine, and rotated by a winch handle or by a motor, the difference in the direction of rotation of the discs being obtained by crossing the alternate belts.

Both discs are well varnished, and attached to the outer surface of each there are radial sector-shaped plates of tin-foil or thin brass disposed around the discs at equal angular distances.

Twice in each revolution the two sectors situated on the same diameter of each disc are momentarily placed in metallic connection with one another by a pair of fine wire brushes attached to the ends of a curved rod, called the neutralising rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate, the sector-shaped plates just grazing the tips of the brushes as they pass them.

The position of the two pairs of brushes with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angle; and there is one position of maximum efficiency. This position in the machine appears to be when the brushes touch the discs on diameters situated about 75° from the collecting combs, and 30° from one another.

The fixed conductors consist of two forks furnished with collecting combs directed towards one another, and towards the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, being along the horizontal diameter of the disc. To these fixed conductors are attached the terminal electrodes, whose distance apart can be varied. Leyden jars are usually fitted to the machine by the makers, but these must be removed, or better, their outer coatings must be disconnected, before the machine is used for treating patients, see § 95.

With a machine having plates 17 in. in diameter there is produced under ordinary atmospheric condi-

tions a powerful spark discharge between the electrodes and these discharges take place in rapid succession so that the stream of sparks seems almost continuous. The machine is very efficient and perfectly self-exciting, provided there are sufficient sectors, generally requiring neither friction nor any outside electrification to start it, and this is one of the most remarkable features of the apparatus, for under ordinary con-

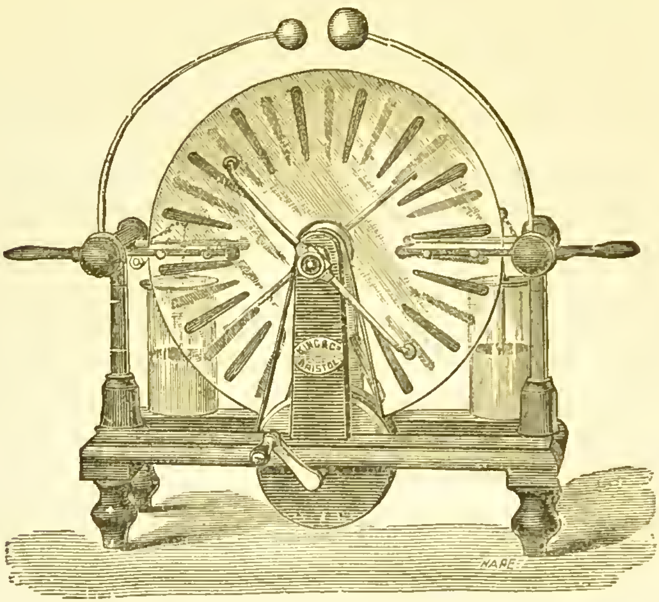

FIG. 53.—Wimshurst machine.

ditions the machine works at its full power after the second or third revolution of the handle. It has been suggested that this initial charge is obtained from the friction of the air, and that chiefly between the plates, but nothing certain is known about it.

When the glass plates are very large they are apt to split. On this account a modification of the Wims-

hurst machine has been made with ebonite plates which are said to be superior to glass, and are not liable to breakage during transit or use, and can be safely driven at a very high speed. There is, however, a grave objection to the use of ebonite, as it gradually deteriorates on the surface and loses its insulating properties; moreover, the plates of ebonite cannot be kept true, but bend and buckle, glass is therefore the best. In choosing a Wimshurst machine for medical use, it is important to have one very strongly put together. The ready made ones are not always fit to stand the hard work which is required of them, and it is perhaps best to have one specially built for the purpose.* The best form is one with eight or twelve plates, of 18 to 24 inches in diameter, and the machine should be enclosed in an air-tight glass case to protect it from the dust, which otherwise is abundantly attracted to the machine, and gives much trouble in keeping it clean. If larger plates are used, the cost of the machine and case rapidly increases. The dimensions here given will suffice for all ordinary treatment if care is taken to diminish as far as possible the losses from leakage.

As Wimshurst's machine is the best in every respect it is not necessary here to describe others, such as Carré's, which is still used in France, and Gläser's which is a modified form of Wimshurst with ebonite cylinders instead of glass plates. This latter machine is made on the model of Clarke's well-known little electric-spark gas lighter.

93. **Conductors.**—Leakage losses are especially apt to occur from the conductors used to connect the patient

* The Electrical Accessories Company, 110 Charing Cross Road, W.C., build very good machines.

to the machine, and anything in the nature of a point at any part of the conductors will dissipate the charge so seriously that there will be but little of it left for the patient (§ 21). These losses can be the less endured because the output of an electrical machine is at best not very great. Metallic chains, silk covered cords, or bare wires all dissipate the charge, either from their ends or from their entire length, and cannot be employed. Thick brass tubing with knobs or knobbed hooks at the ends, or else wire thickly covered with gutta percha may be used for conductors, the latter has the advantage of being flexible, and is recommended.

The arrangements in use at St. Bartholomew's Hospital are shewn in fig. 54. The gutta percha covered wire used is known as cable core, and is a quarter of an inch thick. For attachment to the machine it is provided with knobbed plugs which fit into holes in the prime conductors, and leave no sharp edges nor ends of wire exposed. The conductors then pass through india-rubber rings fixed to cords which hang down from the ceiling, these support the weight of the conductors, and by their elasticity they serve to protect the machine from injury, when as sometimes happens, the patient pulls or jerks at the conductors.

The suspension of the conductors in the air also improves their insulation considerably by removing them from contact with the furniture of the room ; in spite of its thickness the gutta percha insulation is quite likely to be pierced by a spark, if the conductors are allowed to come into contact with any object whose insulating properties are not first rate, and when once accidentally pierced the pin hole which is produced in the gutta percha will act as a point, and dissipate the charge very considerably; fortunately the puncture can be closed by

warming the gutta percha. The cords therefore should not be touched when the machine is in action.

94. **Electrodes.**—The ends of the wire which are connected to the electrodes, or "excitors" as they were

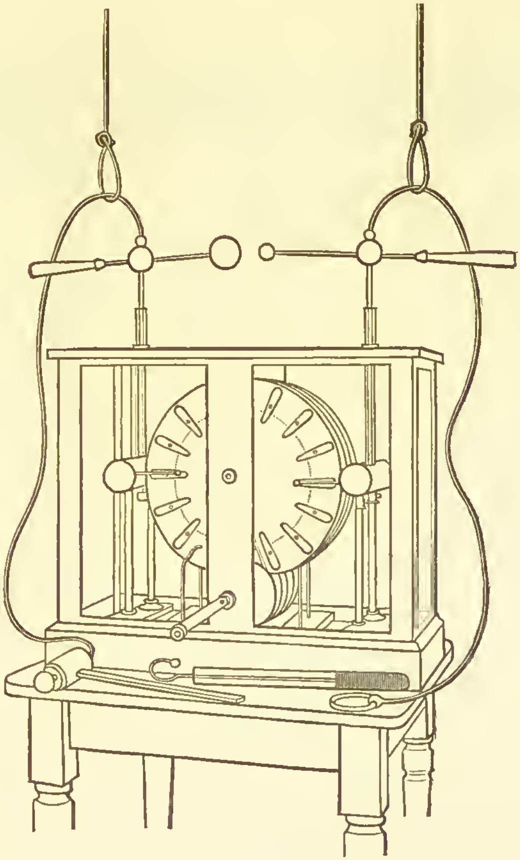

FIG. 54.—Wimshurst machine showing suspended condition.

formerly called, also require consideration. These must be managed so that there are no exposed points, and the accompanying figure shows a convenient method of doing this.

A (fig. 55) is an ebonite handle twelve inches long, polished and varnished with shellac, at one end it is screwed into a short cylinder of ebonite, this is pierced longitudinally with a hole which will just admit the gutta percha covered wire.

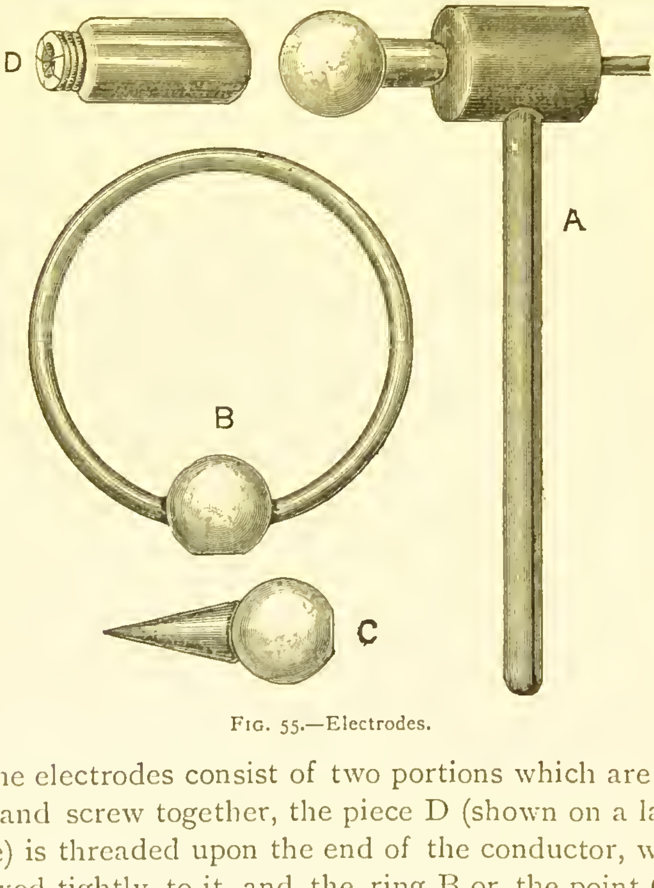

FIG. 55.—Electrodes.

The electrodes consist of two portions which are hollow and screw together, the piece D (shown on a larger scale) is threaded upon the end of the conductor, which is fixed tightly to it, and the ring B or the point C, or the knob (as in A) are screwed on when required. The ring upon one conductor is for the patient to grasp, the handle, fitted with knob or point is attached to the other conductor, and applied by the operator as required.

By using these electrodes the leakage is reduced to a minimum, and the process of treating patients much facilitated.

95. **The Leyden jar.**—This apparatus (fig. 1, p. 26) was discovered in 1749. Owing to the arrangement of its coatings it has a large capacity, and in its discharge there is a larger "current" than in the spark from the prime conductor of a machine as ordinarily constructed.

This makes itself felt as a more severe shock, when the discharge takes place through any portion of the body. The Leyden jar is therefore used when it is desired that the patient shall receive a painful shock. In the illustration of the Wimshurst machine (fig. 53), two Leyden jars are shown with their inner coatings connected to the prime conductors, one to each; the outer coatings are also connected by a wire, which can be removed at will. When the outer coatings are disconnected, or the jars are removed entirely, the machine in action produces a stream of thin purplish sparks, and if the finger be placed between the discharging electrodes, the sensations, though unpleasant, are of the nature of a slight pricking rather than of shock. If the jars are now connected to their respective electrodes, and their outer coatings are joined by the wire, the sparks between the electrodes alter their character, becoming less numerous, much brighter, and much more noisy. They also produce severe shocks if the fingers are placed in their path. As the distance between the knobs of the discharging electrodes is increased the sparks become louder, more vivid and less frequent, until the air gap is too great for the discharge to cross. All these effects are better marked with jars of large capacity than with small ones. If the wire joining the

outer coatings of the jars be interrupted by a short air gap, sparks will leap across it simultaneously with those passing between the electrodes.

Many machines are fitted with a pair of binding screws in the circuit joining the outer coatings of the Leyden jars. This makes it easy to connect or disconnect this part of the circuit. When a wire is used to bridge over the interval between the binding screws the outer coatings are connected, when it is removed they are disconnected. Dr. Morton of New York has advocated the use of this portion of the circuit between the outer coatings for purposes of treatment. With a pair of ordinary conducting cords and electrodes (fig. 56)

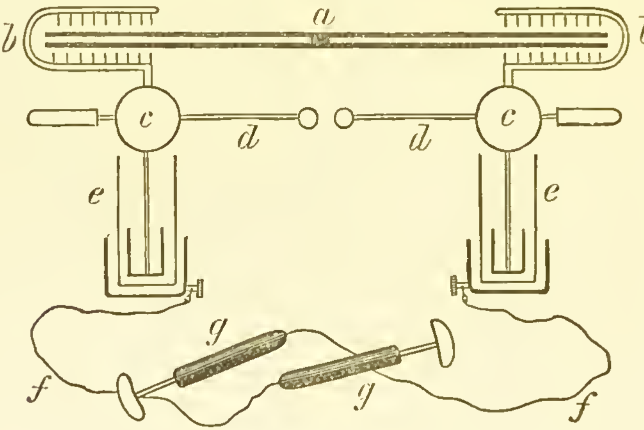

FIG. 56.—Plan of Dr. Morton's method. *a*. Plates of machine. *b*. Collecting combs. *c*. Prime conductors, with discharging rods, *d*. *e*. Leyden jars. *f*. *g*. Wires and electrodes attached to their outer coatings.

attached to the binding screws mentioned above, Leyden jar shocks can be administered to a patient, and their severity can be controlled by adjusting the distance between the discharging knobs of the prime conductors. When the machine is in action a shock is felt by the patient every time a spark passes between the dis-

charging knobs. Dr. Morton has given this method the name of treatment by "static induction," a name to which one might perhaps object on critical grounds, but the utility of the method is undoubted for purposes of treatment. Further, Dr. Morton has claimed that by the use of very small Leyden jars and with the discharging knobs very close together, the shocks become almost painless, while still setting up vigorous contractions in the muscles, and may then be made extremely useful for purposes of testing. It is doubtful, however, whether this method is less painful than the discharge of a well designed induction coil.

If instead of using two Leyden jars, one of them be removed, and be replaced by a simple conductor connected to that pole of the machine, the conditions are practically unaltered. The remaining jar having its inner coating attached to one pole of the machine as before, the circuit may be completed by joining its outer coating to the opposite pole by the wire, and a patient introduced into a gap in that part of the circuit formed by the wire, experiences shocks every time a spark passes between the knobs of the prime conductors.

This arrangement of one Leyden jar with its inner coating connected to the prime conductor, and its outer coating joined to a patient, who is in turn connected with the machine through an adjustable spark gap, is by no means new. The frontispiece of Adams' *Electricity* (date 1791) represents a physician of the period electrifying the fore-arm of a child in this way with electrodes applied to the skin, while a fashionably dressed lady looks on. "Statical induction" then has been known to medical treatment for a hundred years. To Dr. William J. Morton, nevertheless, belongs the

credit of having improved and developed the original mode of carrying it out.

The principle is that of a circuit containing a condenser, and including a patient and a spark gap, both in series with the condenser. The system is continuously charged from the machine, and discharges intermittently across the air gap with sudden rushes of current.

For use with the electrodes described in § 94, a long narrow Leyden jar like a large test-tube may be used in the following manner: the hook which forms the connection to its inner coating is attached to the ring (B fig. 55), and the outer coating is held against the patient or fastened there. The ebonite handle with knob electrode from the other pole of the machine is also placed against the patient, and the discharging knobs being adjusted, the Leyden jar shocks traverse that part of the patient's body which lies in the circuit. It is of the utmost importance to adjust the sparking distance between the discharging electrodes on the machine before commencing the treatment; from an eighth to a quarter of an inch is generally sufficient, indeed, with quarter inch sparks, the treatment is severe. Female patients, indeed, display great fortitude and good temper under Leyden jar treatment, though this is not always the case with men.

96. **The insulated couch.**—An insulated seat is required for most forms of treatment with statical electricity, and the insulation requires very careful attention.

To keep a patient well charged upon a stool or couch taxes a machine to the utmost, the leakage from every point of the patient's hair and clothing and from every sharp point or edge of the couch becoming more and

more rapid as the charging potential becomes higher. The feet of the couch should be supported upon glass supports well varnished with shellac, and raised two, three or even four inches above the ground. A smooth india-rubber mat underneath the feet is also useful. All angles and edges of the couch or chair should be rounded and polished. A horsehair or velvet upholstering is bad, plain polished wood and leather is much better.

If the legs of the chair or couch be made to stand inside of four gallipots well dried and varnished, and having a deep layer of hard paraffin wax inside them, the insulation will be much improved.

97. **Modes of application.**—Patients have been subjected to treatment in almost all the various ways which an electrical machine allows. The positive charge, the negative charge, the administration of sparks, Leyden jar shocks, and the brush discharge were all tried by the earliest experimenters, and their effects described.

98. **Treatment by charging.**—The patient may be treated by insulation and charging, or the so-called dry electric bath (*bain électrique*). This is carried out by placing the patient, who may be fully dressed, on the insulated couch or chair and connecting him to one conductor of the machine. The machine is then set in motion and the patient is charged either with positive or negative electricity according to his condition and requirements. As soon as he becomes charged the patient feels in a curious condition difficult to describe. His hair feels inclined to stand on end and on his face he feels a slight sensation as if lightly touched by gossamer. A general glow is set up, and perspiration is induced. The charging may be continued for varying lengths of time. In the practice of different phy-

sicians it has ranged from ten minutes to three or four hours.

It is probable that from half an hour to an hour is the best time to keep the patient under the influence of the charge. The machine must be kept in action to keep the patient fully charged, when it stops the patient quickly loses the charge and may then descend from the couch. The operation should be repeated

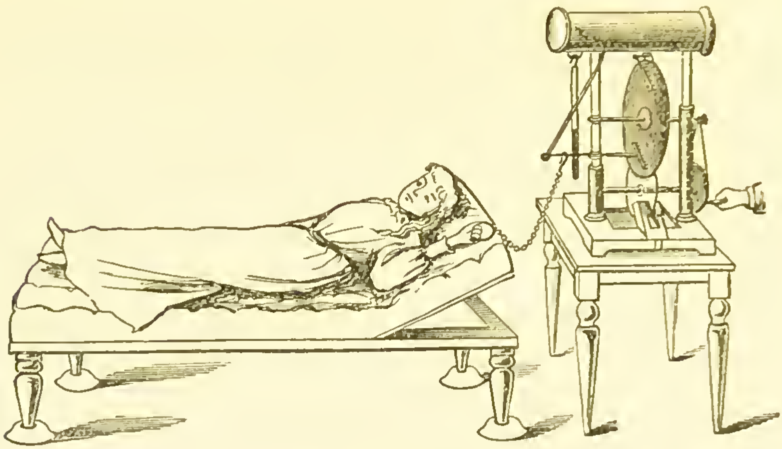

FIG. 57.—The dry electric bath.*

daily for the first week or ten days, then every other day or occasionally as the condition of the patient requires. At the Salpêtrière in Paris, where this treatment is much in vogue, insulating couches are used large enough to hold many patients at once. They are all charged together from two Wimshurst machines driven by motors.

99. **Effects of the positive charge.**—The *positive*

* Although the obsolete machine of Carré is represented in this figure and the next, they are retained as being to a certain extent illustrative of the *modus operandi*.

charge has been found useful in general debilitated and neurasthenic conditions and in many mental states accompanied by a depressed condition of the system, such as some forms of hysteria, melancholia, and nervous insomnia; also in the treatment of spasmodic asthma. The opposite condition, namely a negative charge has been said to have induced an attack of the disease. The negative charge is said to produce a condition of the body as of prostration. It is possible that some of the good results formerly derived from the use of statical electricity did not depend upon the shocks given to the patient but to the associated charging, for as a matter of fact the patients were generally charged positively, since Ramsden's machine, then used, would only produce a positive charge when used in ordinary way.

It is but right to say that most people are unable to perceive any particular exhilaration from the positive charge, nor any depression from the negative, nor can they distinguish whether they are being charged positively or negatively. There are some patients, generally women of nervous temperament, who appear to be able to tell the difference or even to feel it acutely. The sensation of a warm glow and perspiration is commonly perceived by all.

If there be so great a difference between the effects of the poles it becomes very necessary to be able to distinguish them. To do this with the Wimshurst machine in action is easy in a darkened room. On the negative side of a machine the collecting points have fine brushes of purple light, and on the positive side there are bright star like points, while a blunt point fixed on the positive side shows a long brush discharge, and on the negative side a short bright tuft of light.

In the daylight it is possible to distinguish the poles by presenting a finger to the conductors, the negative side will discharge to the finger at a greater distance than the positive and with a different sound. The flame of a long wax taper is mainly repelled from the positive pole and mainly attracted by the negative. With a short lighted match held in the hand the flame is repelled towards the observer's fingers and is very apt to burn them.

When the knobs of the discharger are about an inch apart the stream of sparks between them is whiter and more condensed near the positive knob, violet and looser near the negative knob.

In starting the Wimshurst machine the discharging knobs must be kept separated or it will not excite (the opposite is the case with machines of the Holtz or Voss type). If the machine does not excite readily the ebonite or glass supports of the prime conductors may be wiped and rubbed with a piece of silk, and the neutralising rods moved into a position nearly horizontal; when excitation is obtained, they should be moved back to a position nearly vertical.

100. **Treatment by sparks.**—A second method of using statical electricity is by sparks. Sparks are taken from or given to a patient as follows; the patient is insulated and holds one electrode of the machine. The spinal column or part to be treated is laid bare, and when the patient is charged, the other conductor with knob electrode (fig. 55) is brought near to the patient and a spark is immediately seen to pass between the two. The maximum length of spark can be exactly controlled by the space between the discharging electrodes of the machine, for these are always capable of being separated or approximated to regulate the spark-

ing distance. In this way it is often possible to treat the patient with sparks two, three or four inches long.

A condition of the skin resembling urticaria is set up by the sparks, but it is transient and disappears after five or ten minutes.

A pointed electrode, for obvious reasons (cf. § 29), gives a smaller spark or even only a brush, and the suddenness and violence of the spark can also be increased by an increase in the size of the brass knob used. A modified treatment by sparks is sometimes spoken of as "electrical friction," on account of the

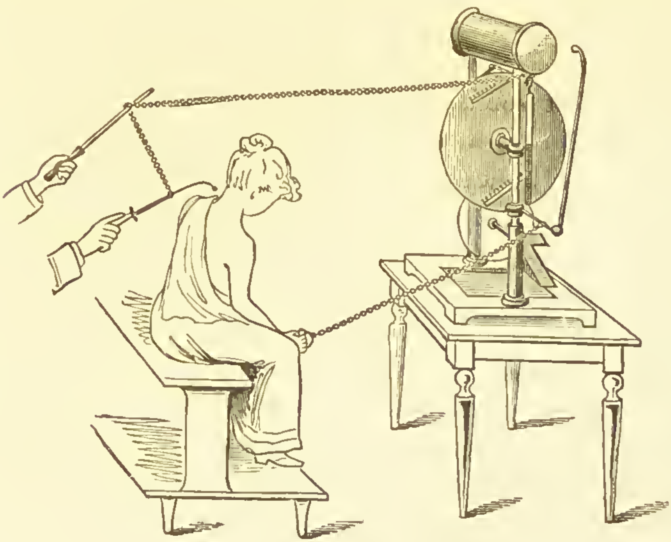

FIG. 58.—Treatment by sparks.

mode of application. The skin being covered with a layer of dry flannel, the knob electrode is rubbed over it; multitudes of small sparks, whose length is determined by the thickness of the flannel, pass through to the skin, and produce a pricking sensation and an effect of brisk counter-irritation.

101. **The brush discharge.**—The electric wind, breeze, brush, or souffle, is produced by bringing a pointed electrode near to an insulated patient, who is being charged. The effect is greater when the patient is charged from the positive pole of the machine and the point is connected to the negative pole. The point may be made of brass or wood. When the comparatively blunt wooden point is used the breeze is not so strong as with the sharper brass one. A hissing sound is produced and in the dark a luminous brush of light is perceptible. The patient feels a pleasant sensation as of a draught of wind playing upon the part under treatment. When a more vigorous souffle is required, an electrode having numerous points is used. The breeze or souffle is useful for the relief of pruritus, neuralgia, the lightning pains of locomotor ataxy, and other painful affections. It is said to have a marked sedative effect, and to be a valuable treatment for eczema.

As the souffle is very agreeable when applied to the scalp, an arrangement of points suspended from a stand is used; this is fixed just above the head, and is called the "statical douche."

102. **Value of the treatment.**—It is very difficult to form a true estimate of the value of the methods of treatment just described. When the object of treatment is to create a strong mental impression, then the electrical machine, with its sparks and its shocks, is of great usefulness, and it is for this reason most excellent for dispelling various hysterical symptoms, such as contractures, aphonia, anæsthesia or paralysis of hysterical origin. Painful hysterical joints or spines also improve under this treatment, often in the most wonderful manner. But in such cases as these electricity acts indirectly, and merely in proportion as it influences the

patient's mind. Its use, though legitimate, has a psychological rather than a physiological value. Putting on one side for the moment all cases of an hysterical nature, it may be asked what else the electrical machine can do? The revival of interest in electrostatic methods of late years, particularly in France, has succeeded in throwing some little light upon this question; Truchot* has reported the results of some experiments upon himself, in which he was charged once or twice daily for a week. Each charging period was of fifteen minutes duration, but it is not specified whether the charging was positive or negative. The points attended to were the pulse-rate, the temperature, and the urine; the force of the grasp was also determined by means of a dynamometer. These points were observed for the week preceding the commencement of the electrifications, and for the week which followed.

The pulse was increased in frequency after each charging, being raised from 65 to 80, but apart from this immediate effect there was also a gradual rise in the average daily rate so that after the fifth or sixth charging the pulse remained at 80 for the whole day, and only began to return to its normal frequency two days after the chargings had been discontinued, finally reaching its normal rate of 65 per minute at the end of a week. The temperature also showed a gradual rise, being 97·9 at the beginning of the treatment, and 99.3 at the end of the week, returning slowly to its former level during the next few days.

The strength of grasp was augmented by each charging, rising from 42 to 44 kilogrammes after the first time; from 41 to 43 after the fourth, and from 40 to 42 after the sixth, but, as these figures show, there was a

* *Archives d'électricité médicale*, Feb., 1894.

progressive decrease in the muscular power during the week of treatment, and the decrease was gradually recovered from during the following week, when charging had been discontinued.

The analyses of the urine, though a little difficult to interpret, show at first an increased proportion of urea to total nitrogen, followed by an increase in the total nitrogen with a fall of urea, which Truchot interpreted by supposing that at first metabolism was increased, and internal oxidation were improved, but that afterwards there was increased tissue waste with less perfect oxidation ; here again the effects of the treatment were perceptible for several days after its discontinuance. His general condition showed increased appetite for the first day or two followed by a diminution; sleep became disturbed, and a feeling of languor and feverishness developed itself. Thinking that perhaps the season of the year (July and August), and the fatigue of the summer session might have contributed to his weariness, the experiments were repeated between Oct. 15th and Nov. 15th, after the repose of the long vacation. The results, however, were precisely the same, the temperature rose from 98·6° to 99° after four sittings. The pulse rose from 64 to 79, the feelings of fatigue returned.

Unfortunately the body weight does not seem to have been taken, and no light is thrown upon the question of the difference between the effects of positive and negative poles.

The brush discharge or *Souffle electrique* with its varieties the *douche* and the *aigrette*, have been tried in the treatment of cutaneous affections, and with good results in obstinate eczema,* in pruritus,† and in chronic ulcers

* *Arch. d'électricité médicale*, April, 1894.

† *Arch. d'électricité médicale*, 1893, p. 309.

of the leg. It also relieves headaches and migraine when applied to the scalp.

The treatment by sparks has chiefly a local stimulating effect and in one or two cases they have seemed to me decidedly useful in cases of paralysis. Leyden jar discharges are now not much in vogue for treatment, on account of the painful character of the shocks, but they may be used for stimulating paralysed muscles in obstinate cases.

There is not very much to be gained from examining the older records of cases treated by electricity, when the electrostatic methods were the only ones in use; for the most part the cases are reported briefly and imperfectly. Those who are interested in this part of the subject should consult the letter of Mr. Birch, already referred to on page 4, as in charge of the electrical department of St. Thomas's Hospital at the end of the last century. Short notes may be found there of a number of cases treated successfully; including four of chronic synovitis, and six of chronic enlargement of the testis (probably syphilitic) which improved rapidly under local treatment by shocks from the Leyden jar. In John Wesley's book (§ 90), many cases are reported, but they are for the most part curious rather than instructive.

103. **Clinical Experiences.**—Dr. Imbert de la Touche has obtained results which tend to support the view that the electrostatic charge modifies the metabolic processes in some way. He has reported cases of obesity cured by this method, and speaks with confidence of its great value in "obesity of nervous origin," particularly when anæmia, headaches, and insomnia coexist.

Dr. Dignat examined the pulse-tension in eleven

patients and found that out of sixty-two observations the tension was raised in thirty-six, remained unaffected in twenty-four, and was lowered in two.

Other writers too have insisted that the electrostatic brush discharge exercises a powerful effect upon the skin, which becomes clearly manifest by the way in which these applications promote the cure of certain cutaneous affections.

Dr. Vigouroux has expressed the opinion that the treatment by electrostatic charge acts chiefly upon the function of nutrition, and upon the nervous system. Sleeplessness, and languor disappear soon after the commencement of the treatment, the appetite too becomes increased ; as for the urine, the urea augments, and the uric acid diminishes, and the flatulent dyspepsia, so common in neurasthenics, is rapidly ameliorated.

104. **High frequencies and high potentials.**— The introduction of alternating currents for commercial purposes, and the ease with which high potentials can be obtained through their use by the aid of transformers makes it possible to subject the body to alternating high potentials and to examine the physiological effects produced. With the electrostatic machine the process of insulation and charging raises the patient's body to a high potential, positive or negative, according to choice, and the potential is maintained during the action of the machine. By attaching an insulated patient to one pole of a high pressure transformer a charge which is alternately positive and negative can be applied to him. The experiment is not to be undertaken without the most careful insulation. If the patient should by any accident become connected to earth during the charging, as might happen in various ways, as for example by being touched by a by-stander,

his body would become the channel for a current to earth which might easily attain a dangerous magnitude; and as a matter of fact many persons have been killed by coming into contact with a high potential conductor when they were not properly insulated from earth. It has been already explained why there is no danger of accident with the electrostatic machine (§ 89) and it is quite possible to arrange matters with the transformer so as to get rid of all serious risk by the use of adequate resistances, or of transformers of very high self-induction and small output. No experiments, however, have yet been made in this direction; and the effects of a high potential charge alternating at the rates usual in commercial currents, ranging between 50 and 120 complete periods a second have yet to be studied.

High frequency experiments. When a charged conductor discharges itself, it happens under certain conditions of the discharging circuit that the discharge is an oscillatory one, that is to say the direction of the discharge current is alternating. These oscillations quickly die away, but while present they may have a periodicity of millions per second.

Of late years Elihu Thomson, Nikola Tesla and D'Arsonval have developed the study of these "high frequency" phenomena, and have obtained some remarkable results. The apparatus required is comparatively simple; the principle is to charge Leyden jars whose outer coatings are connected by a helix of wire, as in figure 59. The inner coatings of the jars terminate in knobs whose distance apart can be adjusted to suit the sparking distance of the charging electromotive force. The jars can be charged from a Wimshurst machine; or from an induction coil of large size, or, through a high potential transformer, from the alternate current supply mains.

The jars when charged to a certain potential discharge across the air gap, and oscillations are set up in the helix connecting the outer coatings, and the helix becomes the seat of electro-magnetic induction effects, comparable to those of the primary circuit of an induction coil, so that wires leading from the two ends of the helix yield a current, as do the wires of the primary current of a coil, § 67. In fact the apparatus is a modified induction coil, the current being supplied from the jars instead of from a galvanic cell while the spark gap takes the place of the contact breaker, and the suddenness of the discharge by causing very rapid changes in the magnetic field of the helix, sets up very powerful induction effects, both in the helix itself (self-induction), and round it, a secondary coil wound over the helix giving very conspicuous effects. D. D. in the figure represent two persons holding between them an incandescent lamp L., and having their other hands connected to the terminal points of the helix, under these conditions the current through the lamp traverses the arms and trunk of the two experimenters and the lamp glows brightly, though they feel no shock.

It is usual to place the helix in a vessel of oil, to insulate it and prevent sparks from passing between the neighbouring turns. If a secondary coil be wound on a wide glass tube placed over the primary to prevent sparks from passing between primary and secondary, a stream of crackling sparks several inches long will pass between the terminals of the secondary coil, but when the body is placed in the circuit little or no shock is felt, but only a warm glow and a partial anæsthesia of the region in contact with the electrodes.

This experiment and others of a similar nature have given rise to a belief that with high frequencies of

alternation there is no danger even if large currents are passed through the body.

That the current through the lamp must have been two ampères, as estimated by D'Arsonval, is almost incredible, for a current of that magnitude from any ordinary source of electrical currents, whether direct or alternating, would destroy life, and produce serious burns of the tissues at the points of contact.

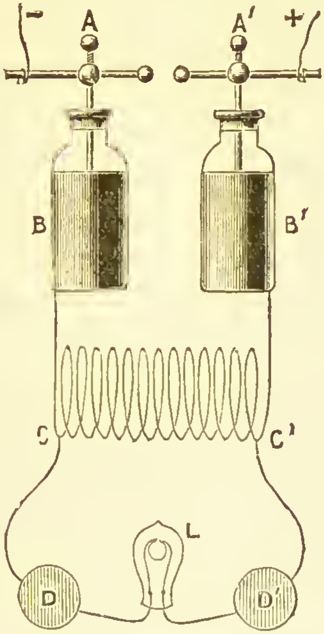

FIG. 59.—Arrangement of apparatus for high frequency experiments.

One suggested explanation of the incandescence of the lamp filament is that at very high frequencies the resistance of the filament is enormously increased, and a much smaller current at a proportionately higher voltage will make it glow. Another explanation given is that the rushes of current are very large while they last, but have so brief a duration that the total current

passing in a given time is comparatively small; this, however, does not explain the difficulty of the absence of shock. Others, again, incline to the belief that the energy dissipated at the lamp filament is not so much an electrical current as a molecular disturbance, or "bombardment," and that the actual current may be remarkably small. This is supported by the incandescence of a lamp when fixed to one electrode only of a high frequency coil, here the true current must be quite small and yet the lamp glows.

It is a fact, probably a very significant fact, that although with a high frequency apparatus no shock is felt when the hands are in good contact with the electrodes, yet if there be an air gap in the discharging circuit the shocks at once become severe, and the wider the gap the more severe are the shocks. This observation made in the course of some experiments in the house of Dr. Hedley in Brighton, is not alluded to in the published accounts of D'Arsonval's experiments. Dr. Hedley has further shown that if the electrodes in contact with the skin are progressively diminished in area a point is reached with small sized electrodes, when a distinct sensation becomes perceived, and he has very rightly argued that if the rapidity of alternation be the only factor which makes the current imperceptible, it should be as little felt with electrodes of small surface as with those of large surface.

The progressive increase of sensory effect as the area of contact is diminished, suggests that the concentration or density of the current is an important factor, and this again makes it probable that the total actual current flowing must be one of very small magnitude.

These paradoxical effects have given rise to much discussion, but further investigation is necessary before the real explanation of them can be arrived at.

Accounts of D'Arsonval's investigations, with illustrations of the arrangements of his apparatus will be found in the French Electro-therapeutic Journals for 1893 and 1894, and in the *Electrical Review*, March 23rd, 1894. It is not necessary in this place to consider them at greater length because they have not yet come into practical use for medical treatment.

Further investigations by competent physiologists are much needed in this as in many other parts of the subject.

CHAPTER VI.

Physiology.

The resistance of the body. Diffusion of current in the body. The action of electrical currents on living tissues. The motor nerves and muscles. Unstriped muscle. Sensory nerves. Refreshing action. Trophic effects. Electrical osmosis. Lethal effects. Magnetism.

105. **The resistance of the body.**—The body is a conductor exactly in the same way as saline solutions or moist sponges are conductors, that is to say, it is an electrolyte, and the tissues between the electrodes during the passage of a current are in exactly the condition of the liquids in an electrolytic cell, consequently the passage of the current causes the accumulation at the positive electrode of acids, chiefly hydrochloric, from the abundance of sodium chloride in the juices of the body, and of bases, chiefly soda from the same reason, at the negative electrode. The region between the poles shows no evidences of either free acid or free alkali, and yet we feel sure that exchanges must be taking place all through the chains of molecules between anode and kathode. Moreover, it is not reasonable to assume that the changes only occur in the fluids of the intercellular spaces, for they must also go on in the whole of the cell substance which is traversed by the current.

Dr. Stone,* in a careful study of the resistance of the

* Lumleian Lectures, 1886.

human body, arrived at the figure of one thousand ohms as the average resistance from foot to hand, and from foot to foot, when the contacts were made through large vessels of salt water into which the extremities were plunged. In this way he thought he had succeeded in eliminating the resistance of the skin, and considered that the figures obtained indicated the resistance of the deeper tissues only.

Professor G. Weiss,* measuring the resistances from hand to hand with contacts made through bowls of salt water, found the average resistance in sixteen men to be a little over thirteen hundred ohms, and in seven women fifteen hundred ohms, the reason why the latter showed a higher figure is not very clear, particularly as the skin of women is generally believed to be more thin and delicate than that of men. It may have been due to the smaller surface of the hands of the women, or perhaps to a lesser number of sweat glands and hair follicles; the difference, however, is not great, and would probably be less apparent if a larger number of cases had been measured.

In some measurements made in the *post-mortem* room at St. Bartholomew's Hospital, the resistance of the tissues, not including the skin, was found to range between two hundred and four hundred ohms.

Different observers have given the most widely divergent figures for the body resistance, the range being from one thousand to two hundred thousand ohms, according to the nature of the contacts used in the experiments. The human epidermis, when dry, offers a very high resistance indeed, especially if it be at all thick and horny like that of the palms of the hands and

* *Arch. d'électricité médicale*, 1893.

the soles of the feet. When moistened and permeated with water or salt solution, its resistance becomes much less; the tissues of the body have a comparatively low resistance, and the only value of most of the experimental determinations of resistance is that they show how enormously the resistance of the skin may vary. The resistance offered by any patient depends upon the following points. *First*, the state of the skin, whether thick or thin, dry or moist, cold or warm. *Second*, the area of the electrodes and the efficiency with which they are brought into contact with the surface of the body. *Third*, the electromotive force of the battery used in the test; and *fourth*, the duration of the test. With low electromotive forces, one volt for instance, the resistance is much greater than with higher voltages, and polarisation becoming set up at the surface of the electrodes tends to make the apparent resistance even greater than it really is. With higher voltages the passage of the current produces at first an increased vascularity of the skin under the electrodes with diminution of the resistance, and if the current be continued, so as to cause the skin to be gradually destroyed, the resistance is further diminished.

During the progress of treatment the number of cells in circuit must be reduced gradually to compensate for the fall in resistance, if this is not done there is a risk lest the current should rise to too high a figure, and injury may result to the patient from want of attention. Burns of the skin are sometimes produced in this way.

The resistance of a patient is almost entirely a resistance at the contact of the electrodes with the skin, it can be varied in many ways, and it does vary from day to day in the same patient. As for the resistance of the tissues beneath the skin, it is a matter of a few

hundred ohms. Careful measurements of the resistance of patients, and statements as to the degree of resistance in different morbid states cannot therefore be of much value or importance.

When the electrodes are applied to mucous surfaces, or are in the form of needles thrust through the skin, the resistances are much lower. With needles of both poles inserted into a nævus, the resistance may be as low as a hundred ohms, and it is said that with needles in an aneurysmal sac readings as low as ten ohms have been recorded.

The medical practitioner is concerned with the resistance of the body mainly as it affects the question of treatment, and the number of cells required to drive the proper current through the patient. Under conditions of medical practice, and using moistened electrodes, the resistance of the body, when the skin is well wetted with warm water, is about two or three thousand ohms, that is to say an electromotive force of twelve volts (eight Leclanché cells) will pass a current of four to six milliampères. If one electrode is placed on the palm of the hands the resistance will be at least double. Difficulties in testing muscle sometimes occur from not remembering this point, for an electromotive force with which contractions are easily set up in the muscles of the forearm and of the back of the hand, may produce no effect at all when the testing electrode is transferred to the palm. A glance at the galvanometer will, however, show the reason why, by indicating a smaller current and a greatly increased resistance.

The excessive resistance which is sometimes offered by the thick dry skin (especially of patients who have been long confined in bed, and when there has been little or no perspiration for some time) occasionally pre-

sents a considerable obstacle to the electrical examination of their muscles, and unless care is taken, it is apt to mislead.

During the treatment of a patient the resistance of his body may be calculated by Ohm's law from the galvanometer reading, and the electromotive force of the cells if that be known. For example, with twelve Leclanché cells in good order the electromotive force will be eighteen volts, and if the current through the patient be four milliampéres the resistance may be taken as follows:—$R = \frac{E}{C}$, $E = 18$ volts, $C = {\cdot}004$ ampère, therefore $R = \frac{18}{{\cdot}004}$ or 4500 ohms. When exact measurements are required a Wheatstone's bridge arrangement, with a battery current and a galvanometer, or with an alternating current and a telephone (Kohlrausch's method), must be employed (see references given in § 37, or Kempe's *Handbook of Electrical Testing*). The latter method has been preferred, because it eliminates the difficulty of polarisation, but this has probably been over-estimated, and the telephone method introduces other difficulties of its own. Professor Weiss' paper* indicates a method of overcoming the difficulties of polarisation, when the battery and galvanometer method is used.

106. **Diffusion of current in the body.**—The density of the current (§ 38) and the diffusion of the current as it passes through the tissues from one electrode to the other, have an important influence upon the results produced. It has already been stated that in large and heterogeneous conductors, like the human body, the current spreads out in sheets as it

* *Loc. cit.*

passes from anode to cathode. Dr. De Watteville has very clearly illustrated this as follows:—He says: "The reader may picture to himself the electrical density at any point of a circuit of variable diameter by representing the strength of a given current flowing through it by a certain number of lines. These lines expand in the wider portions of the circuit owing to the diffusion, and become crowded together in the narrower parts. A crowd issuing through a narrower door, and through gradually expanding passages, and finally reaching the street, like electricity flowing through a circuit of variable diameter, is said to be densest at the narrow exit, and it thins out, and has a lower density as it reaches the wider outlets."

The path of a current between two electrodes placed upon the body surface is not to be marked out simply by drawing direct lines from the one to the other, for the whole of the conducting tissues between the electrodes help to provide a passage for the current, which spreads out from beneath the positive electrode, becoming less and less dense as it occupies a wider and wider sectional area of the conductor, and again grows denser as its lines of passage become once more gathered together to reach the negative electrode.

Fig. 60 shows the divergence of the directions of these lines of current as they pass from a positive electrode placed upon the back of the arm to reach the negative electrode placed somewhere upon the trunk, and it very well illustrates the fact that the current is not confined to the space directly between the electrodes, for some of the lines which indicate its direction, actually commence their course by curving downwards through the tissues below the electrode.

It follows that parts of the body which are outside

the direct line of the electrodes may be influenced by the current passing between the electrodes, and it will be seen from the chapters on treatment that this may sometimes be advantageous, and sometimes the reverse.

It also follows that the size of the electrodes is of importance in treatment, for at the surface of contact of a small electrode the density of current per unit of surface, when a definite quantity of current is flowing, will be greater than when large electrodes are used; this point has been already alluded to in § 78, and will be again referred to later.

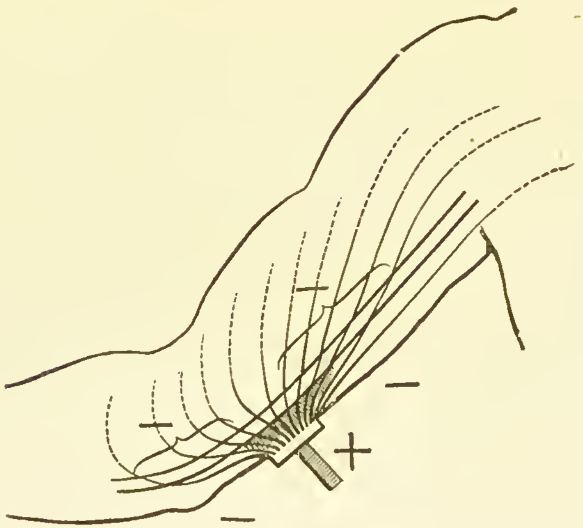

FIG. 60.—Lines of current diffusion round an electrode.

107. **The sensation of shock.** — The effect of electric currents upon the nervous system seems to depend partly upon the magnitude of the current, and partly upon the rate of change in this magnitude. It is possible to tolerate the gradual introduction or the steady passage of twenty or thirty

milliampères through the body if the contacts with the skin at the electrodes are large and good, but the sensation of shock is severe, if currents of five milliampères are rapidly set up in the body; and when the current is broken rapidly its sudden cessation also produces a far greater impression than that felt while it is running steadily. This shock at the break or opening of the circuit is difficult of explanation, and nothing comparable to it is observed with inanimate electrical circuits or apparatus, for it is not of the nature of an induction effect; the explanation which is offered in physiological textbooks, namely, that a sudden fall of potential is an effective stimulus to a nerve fibre is no explanation at all.

The important part played by the rate of change of current in producing physiological effects is clearly shown by what has just been said of the current slowly or suddenly made and broken through a circuit which includes the body; the part played by the quantity of current passing is seen by a comparison of the effects of a spark drawn from the prime conductor of an electrical machine with that from a Leyden jar discharge. A spark a quarter of an inch long taken from the former produces only a slight impression, but a spark of the same length from the jar gives a violent shock. The difference between the two is largely a difference in quantity of current passing. In both cases the electromotive force is very high, and the total quantity is small; but, in the case of the Leyden jar there is, for the extremely brief instant of the discharge, a fairly large current, because of its capacity (§ 95) as a condenser.

108. **Electrical phenomena of nerve and muscle.**—Nerve acts as a conductor, whether it be alive or dead, but there is a peculiarity in its conductivity which

is unlike that of saline solution, viz., its resistance in any direction does not depend solely upon its sectional area as would be the case in homogeneous conductors, but it conducts more readily along the length of its fibres than across them, and the same peculiarity is also found in muscle and in wood.* Brenner has shown that in nerve the transverse resistance is as 5 : 1, and in muscle as 9 : 1, as compared with their longitudinal resistances. It is probable that these differences in resistance simply signify that as conductors they are not homogeneous. Crushed nerve is also said to be a better conductor than fresh undamaged nerve.

Electrical currents in nerve and muscle.

a. Current of rest.—If the wires of a sensitive galvanometer be attached to two points in a removed portion of either nerve or muscle, the existence of a current will be made manifest by the deflection of the galvanometer needle, its direction being that which indicates a current passing through the wire from the central part of the piece of nerve to its extremities; this current is called the *current of rest.* It is more easily demonstrated in an excised and therefore damaged portion of nerve or muscle than in a part which is still lying uncut in the body; and indeed it is probable that this current of rest only exists in damaged tissue, and is not present in normal parts at all, but that it is set up by chemical changes resulting from the injury.

b. Current of action.—If while the galvanometer is attached to it, the nerve or muscle be stimulated in any way, whether by electrical, mechanical, chemical, ther-

* This may well be compared with the phenomena of the conduction of heat in wood, which takes place at a different rate according to the direction of the grain of the wood.

mal, or any other means, then the galvanometer needle will give evidence of the production of an electrical current by a momentary deflection in the opposite direction to that produced by the current of rest; this has been called the *negative variation* of the current, or the *current of action.* It is propagated in both directions from the point stimulated, and travels in nerve at the rate of 28 metres per second, and in muscle at three metres per second, that is to say, the disturbance of equilibrium producing the current moves at these speeds, which are very much slower than the rate at which an electrical current travels along a nerve, which is an entirely different thing. The impulse which passes along a nerve to cause muscular contractions or sensory impressions is not an electrical impulse, although there is an electrical change associated with it. If a nervous impulse were simply an electrical current it should be transmissible by an electrical conductor, as for instance a copper wire, but it is not so transmitted, neither will a piece of damaged nerve convey a nervous impulse, although it may readily convey an electrical current, moreover, the velocity of an electrical current in a conductor, such as a nerve trunk, is immensely more rapid than the velocity of a nervous impulse in a nerve trunk. In muscle the current of action is propagated at the rate of three metres per second.

109. **Electrotonus.**—During the passage of a constant current along a nerve certain alterations in the irritability of the nerve, and certain alterations in its conductivity are produced, this altered state is known under the name of *electrotonus.* Electrotonus then is the condition of a nerve during the passage through it of a constant current, but the effects in that part of the nerve near the anode are not the same as those near the

kathode, thus there is one altered state round the anode or *anelectrotonus* and another different altered state round the kathode or *kathelectrotonus.*

a. Anelectrotonus.—In the region of the anode the *irritability* of the nerve is diminished, the fall in irritability taking place at the moment when the circuit is closed, and remaining diminished till the circuit is again opened, when there is a return to the normal. Also the *conductivity* of the nerve for nervous impulses becomes diminished by the development round the anode of a resisting area through which nerve impulses pass only with difficulty.

b. Kathelectrotonus.—Round the kathode the closure of the circuit causes a *rise of irritability* which is maintained during the passage of the current, and returns to the normal level when the current has ceased to flow. The sudden rise of irritability at the kathode on closure is a stimulus to the nerve, and so also in a less degree is the rise from a diminished irritability to the normal at the anode on opening. The importance of electrotonus partly lies in the explanation which it affords us of the behaviour of muscle towards constant currents, at their make (closure) and break (opening). Electrotonus is also useful medically in giving us a clue to the treatment of disease, accordingly where it is wished to increase the irritability of a part the condition of kathelectrotonus should be set up by applications of the kathode, and conversely the application of the anode is to be preferred for inducing a state of diminished excitability, and so of relieving pain and spasm.

110. **Ascending and descending currents.**—When the electrodes are so placed that a line drawn from the positive to the negative pole runs in a direction from centre to periphery, the current may be

spoken of as a "descending current," and conversely it may be called an "ascending current," when the anode is more remote and the kathode more central.

In the case of a nerve trunk which has been exposed and isolated, the conditions are different from those which exist in the case of a nerve which is being tested *in situ*, surrounded by other conducting tissues. In fig. 60 the lines of flow of current round an electrode are shown, and it is clear that they are not all parallel to one another, and that they traverse the nerve trunk in many different directions.

For this reason it is now more usual to define an electrical application, not by speaking of the ascending or descending direction of the current, but by reference to the sign of the pole which is used as the active electrode, and inasmuch as the indifferent electrode is commonly applied to the trunk while the active electrode is applied to a limb, the current would usually be a descending current when the active electrode was negative, and ascending when the active electrode was positive.

The expressions "ascending" and "descending" current convey the idea that the direction of the flow in the interpolar region is of importance, while the phrases "the use of the negative pole," "the application of the anode," and so on, need not necessarily be taken to do more than signify the polarity of the electrode applied to the affected part.

Reference to fig. 60 not only shows that the lines of flow are in all directions, but that the current in traversing any particular point must leave it with a polarity opposite to that with which it enters it, for example, the nerve trunk represented in the figure as traversed by the current is negative to the parts which lie nearer to the electrode, and is positive to those

which are further away. All that can fairly be said of the region surrounding the positive electrode is that it is positive to areas which are more remote.

III. **Reactions of nerve and muscle.**—*a. Battery currents.*—The phenomena of the contraction of muscles when their motor nerves are stimulated by electrical currents are as follows:—If the indifferent electrode be placed upon any convenient part of the surface of the body, and the active electrode be then applied over a motor nerve, it will be found that with a current of one milliampère from a battery, muscular contractions begin to be produced as the circuit is closed, and with somewhat stronger currents contractions appear both at closure and at opening. With the active electrode negative the contraction at make or closure is easier to to produce than when it is positive. The order in which they appear are:—

a. Kathodal	closing	contraction	(KCC).
b. Anodal	,,	,,	(ACC).
c. Anodal	opening	contraction	(AOC).
d. Kathodal	,,	,,	(KOC).

The symbols affixed are commonly used for convenience to designate the contractions, of these *b* and *c* require about twice the current necessary to produce *a*, while *d* requires four times as much.

The exact current needed to produce contractions varies with the excitability of the nerves, and with their position, a nerve which is superficially situated requires a smaller current than a deep seated one, because it receives a greater fraction of the current, as in the latter case the current is more diffused before it reaches the nerve, so that only a part of the current indicated by the galvanometer is effective. For the same reason a patient with a thick layer of subcutaneous fat requires a

larger current to affect his nerves than is the case with a lean person in whom the electrode can be brought into close proximity to the nerve to be tested. The electrode should be small in these experiments, as this allows us to concentrate the current more effectually upon the nerve. There is probably not very much difference in the irritability in different nerve trunks, but perhaps the facial nerve may be slightly more irritable than the others. At least the facial muscles can be thrown into contraction by smaller currents than those of the trunk and limbs, and when they are to be tested it is well to bear this in mind and so to save the patient some discomfort.

Dr. Verhoogen* gives the following figures for the contractions produced by stimulating the ulnar nerve at the back of the internal condyle of the humerus.

KCC	2 milliampères.
ACC	3 ,,
AOC	3·5 ,,
KOC	15 ,,

And these may be taken as representing very well the approximate magnitudes of current necessary to evoke the contractions of healthy muscles through their motor nerve trunks.

These figures are of value because they give the actual effects observed in a particular case, but they seem to be rather high, other observers have found 1 milliampère to be a sufficient magnitude of current for producing the minimal KCC contraction in superficially placed nerves.

It will be seen in the next chapter that it is convenient to make use of certain nerve trunks which can easily be reached when the irritability of the motor

* *Revue internationale d'électrothérapie*, September, 1894.

nerves is to be tested. Those generally used for the purpose are the frontal branch of the facial nerve, the spinal accessory in the neck, the ulnar, and the peroneal ; a standard size of electrode should also be used, and a disc three-quarters of an inch in diameter (about three square centimetres) is a suitable one.

In a normal muscle the effect of direct stimulation of its fibres is concealed by the effect produced upon it through its nerves, for the intramuscular branches of its nerve both receive the impression better, and transmit it to all parts of the muscle more rapidly than the muscle fibres could do it by themselves if no nerves were present. Still muscle *per se* is irritable and capable of responding to stimuli by a contraction; but for this it is necessary that the stimulus should have a certain minimum duration, rather longer than the minimum for a nerve trunk, accordingly it often happens that a muscle whose nerves have undergone injury may not respond to the rapid stimuli of induction currents, while they will still respond to the constant current slowly interrupted (see following chapter, "Reaction of Degeneration").

The contractions produced in muscle by the stimulus of the make and break of a constant current are momentary single contractions, and between the contraction at make and the contraction at break the muscle is quiescent and relaxed, although the current is traversing it. With strong currents of ten milliampères or more a condition of imperfect tetanus is produced, which has been named duration tetanus. Anodal duration tetanus, A.D.T., is less common than kathodal, K.D.T. The duration tetanus is not usually seen in electrical testing, but in certain altered conditions it is more readily elicited than in health, and it will be considered in the next chapter.

If the makes and breaks of a battery current follow one another in rapid succession, the muscle passes into a state of tetanus or permanent contraction ; provided the individual shocks succeed one another at the rate of twenty per second or upwards.

b. Induction coil currents.—As the discharge from an induction coil consists of a series of impulses or waves of current, unidirectional in the primary, § 67, p. 90, but alternating in the secondary coil, and occurring about fifty times a second, it is reasonable to expect that their effect upon a motor nerve would be to throw the muscles into a tetanic contraction, and that is what is observed. If the apparatus be arranged to give single shocks, single contractions follow, exactly like those at the make and break of a battery current, in fact, each wave of current from a coil may be regarded as a make followed immediately by a break, the two contractions being fused by the comparative slowness of a muscular contraction, which occupies one-tenth of a second. The rise and fall of the wave with the coil are less sudden than the rise or fall when a battery current is made or broken. The opposite of this is frequently asserted, but it is not correct, for the current from a battery both rises to its full value and falls again instantaneously, while the rise and fall of a current from a coil is gradual, as shown by figs. 26 and 27, and may occupy a period of one-hundredth of a second. It has already been said that the effect upon the muscle is the same whether the stimulus be applied through the motor nerve trunk, or through the muscle itself. Under conditions of health, stimuli to the muscle are really stimuli through the motor nerves of the muscle. In electrical testing it is usual to apply the electrodes to the muscles directly ; the individual behaviour of the muscles is then more

clearly seen than if they be thrown into contraction in groups through a common motor nerve trunk.

When an animal has been poisoned by curare, the nerves are paralysed, and stimuli applied to the muscle till produce contractions, though stimuli to the nerve trunks do not. Under these circumstances the muscle reacts both to induction coil currents and to battery currents, but the contraction produced by an electric shock is more sluggish than in a healthy muscle. It is not certain, however, that curare may not of itself alter the character of a muscular contraction, at least we are not justified in supposing that this drug permits of a complete distinction between the effect of electric shocks on nerve and on muscle. After section and degeneration of the nerve trunk the character of the muscle contraction becomes altered, as will be seen in the next chapter, but here too the alteration may be due to changes in the muscle as well as to the change in the nerve.

112. **Unstriped muscle.**—The effect of electrical stimulation upon unstriated muscle is not so sharply defined as with striped muscle. The general effect is that stimuli from either the continuous current, or the induction coil will set up a wave-like contraction, which is slow and sluggish, and tends to spread for a considerable distance from the point stimulated. The most effective method of setting up contractions in unstriped muscle appears to be by means of battery currents interrupted slowly. A long and careful account of the action of electricity upon unstriped muscle will be found in Onimus and Le Gros,* based upon experiments on animals, but the conclusions arrived at are a little complicated and difficult to follow. They

* *Traité d'électricité médicale*, Paris, 1888.

state that when peristalsis is present it may be arrested by an ascending, and quickened by a descending current; they also noticed that arrest of movement may occur in the region between the poles, together with contraction at the seat of the electrodes.

113. **Heart muscle.**—The habits of heart muscle are peculiar in their highly developed tendency to rhythmic contraction; electric stimulation tends to strengthen the action of heart muscle if it be timed to suit the natural rate of the rhythm; if the stimulation does not quite keep time with the heart beat it may effect a gradual change in its rate, until the heart may be brought to beat in time with the rate of the stimulation. If the stimulation be quite out of step with the rhythm of the heart it will tend to embarrass its action. A weak or moderate continuous current or a smooth unbroken succession of induction coil shocks may strengthen or accelerate the beat of the heart. Strong continuous currents destroy the rhythm of the heart, and cause it to stop in diastole, see below, § 120, and strong shocks from an induction coil do the same. The useful employment of electricity to strengthen a heart which has suddenly developed signs of failure is very difficult, and there is considerable risk of doing the patient more harm than good by injudicious electrification.

114. **Sensory nerves.**—Just as the electrical stimulation of motor nerves causes muscular contractions, so the stimulation of sensory nerves produces sensations. Accordingly, when an ordinary mixed nerve trunk is stimulated, its motor fibres set up contractions in the muscles supplied by it, and its sensory fibres convey to the brain of the patient experimented upon a peculiar sensation or *shock*, strong or weak, in proportion as the

current is strong or weak. The peculiarity of the sensation also produces a mental effect, so that different patients appear to vary in their susceptibility to these sensations, thus it is said that if a current be transmitted from hand to hand through a line of people, some will say they felt the shock severely, and some only slightly.

a. The battery current.—In the case of the constant current, there is a sensation not only at closure and opening, but also during its steady passage, if the current be fairly strong, but not if it be weak.

The sensations are more perceptible at the kathode than at the anode, but a good deal depends upon the relative sizes of the electrodes; if one be much smaller than the other, then the greater density of current at the smaller one increases the cutaneous sensations there. If the electrodes be held still in one place, other sensations of a burning character soon become felt, and are accompanied by reddening, urticaria, or blistering of the surface, these changes and the burning pain are due to the formation of products of electrolysis. In the removal of hairs by electrolysis, the fine needle-like electrode introduced into the hair follicle, feels much as though it were very hot. The nature of the surface of the electrode also modifies the sensation; and the current is less painful when the electrodes are firmly pressed upon the surface, because the contact is then better and the current is distributed over more points of entrance.

Bare metal electrodes applied to the skin produce injury to its surface more quickly than do those covered with a layer of moistened wash-leather or flannel or the like, because in the former case the products of electrolysis are set free at the actual surface of the skin, while

in the latter they are formed chiefly in the moist material which covers the electrode. With battery currents care must be taken to protect the skin from all accidental contacts with bare metal.

b. Induction coil currents.—A single discharge from an induction coil produces a sensation like that of a sudden make or break of a battery current, the severity of the shock depending upon the electromotive force and current in the circuit. An induction coil, with its contact-breaker in action, produces a series of shocks in which the individual impulses may be perceived, unless they follow one another too rapidly.

At fifty interruptions per second the sensations begin to become fused, and at higher rates of vibration the sensation feels more smooth or continuous than before. With rapid vibrations, one hundred per second and upwards, a benumbing effect becomes noticeable in the area of distribution of a cutaneous sensory nerve, if the electrode be applied to a point upon its trunk; this sensation of numbness being additional to the effect felt in the place of contact of the electrode. With a small movement of the electrode away from the nerve trunk the numb feeling may disappear. The numbness is a true anæsthesia, both tactile sensations and the perception of painful impressions being very greatly blunted, and a glow accompanied by perspiration often succeeds, when the current is cut off.

When an electrode is moved over the surface of the skin systematically, the position of the cutaneous nerves can often be exactly localised, by using a very small electrode and a current which can just be felt, for whenever the electrode comes close over a sensory nerve trunk the sensation at once becomes quite strongly felt; from this it appears that a nerve trunk is more sensitive

to the stimulation than the nerve endings are. In testing muscles it is of advantage to know the position of these "sensory points," in order to avoid them and save the patient from unnecessary pain. On the dorsum of the foot there are several, which are apt to become painfully stimulated when testing the electrical reactions of the interosseal muscles. A little exploration of one's own cutaneous surface affords the best way of learning the position of these superficial nerve trunks.

It is stated by Erb that the perception of the induction coil current is a function similar to the perception of painful sensations, rather than of tactile. This can be clearly seen in patients who have analgesia, without loss of tactile sensibility. This was very well illustrated in a case which recently came under my notice, the patient who could feel the touch of the electrode quite well, felt no shock at all even with very strong currents, and she was also unable to feel painful sensations when tested in other ways over the affected area.

Perhaps the word "shock" should really be confined to those forms of electrical sensation in which there is muscular contraction, for the muscular sensation contributes largely to the peculiar feeling connoted by the word shock.

115. **Nerves of special sense.**—The nerves of special sense respond to electrical stimulation by their own special sensations, thus stimulation of the olfactory nerve produces a smell "like phosphorus," and stimulation of the optic nerve produces the impression of a flash of light. The optic nerve seems to be remarkably sensitive to small electrical currents, and the sensation of a flash of light is very easily produced by the small current obtained from a silver coin and piece of zinc put into the mouth, between the gums and cheek. When the metals are made to touch, the optical effect is dis-

tinct. Some observers have even thought that the colour of the flash seemed to depend upon the direction of the current, and that the kathodal closure gave a reddish colour and anodal closure a bluish one. These effects can be fully studied by a battery of four or five elements, with one pole at the nape of the neck and the other over the temple or eyelids. The accident which befell Duchenne, who applied a current of unknown strength to a patient's face, and apparently caused very serious damage to the sight of one of his patient's eyes, described at length in *Électrisation localisée*, 3rd edition, p. 15, may have been a retinal hæmorrhage due indirectly to the electrical application.

The auditory nerve.—This nerve also can be made to respond to galvanic stimulation. It is not so very easy in healthy individuals to produce the electrical reactions of the auditory nerve, for fairly strong currents are required, and some of the effects upon the eyes and brain make the experiment unpleasant; but the investigation is important, because of its bearing upon the treatment of *tinnitus aurium*, as the prognosis in any particular case turns largely upon the way in which the auditory nerve reacts. There is a close likeness between the formula of the auditory nerve and that of the other nerves. The kathodal closure produces a sensation of sound, which may continue during the passage of the current, but the anodal closure does not; on the other hand the anodal opening produces a sound and kathodal opening does not. The formula then is:—

KC sound.
KD sound.
KO —
AC —
AD —
AO weak sound.

These auditory phenomena will be again referred to in a later chapter.

Galvanic stimulation of the nerves of taste is easily produced, and the simple experiment just mentioned for producing the optical sensation of a flash of light will at the same time produce a metallic taste, and by passing a current from one pole at the back of the neck to the other below the chin over the hyoid bone, the same metallic taste is produced.

116. **Other organs.**—Besides the physiological action of electricity upon muscle and nerve, it has an action on secreting glands, upon certain viscera, and upon the brain. It is quite in accordance with what one would naturally expect that a current passing through a secreting gland or through its secretory nerves should cause increased secretion ; and that a current passing through a viscus containing unstriped muscle should cause peristaltic contractions of that viscus, and there is no need for us to enter into detail at present by describing the particular behaviour of the uterus, of the bladder, or of the intestine, for these points will be better treated of later.

In the case of the brain experimental physiologists have made much use of electrical stimuli for determining the situation of motor centres in the exposed cerebral cortex. When a continuous current is passed transversely through the skull, with the electrodes on the temples or mastoid processes, there is a disturbance of equilibrium, a feeling of giddiness, or an actual unsteadiness, with a tendency to fall towards the side of the anode, and sometimes there is conjugate deviation of the eyes to the side of the kathode, with a kind of oscillation or lateral nystagmus.

It has been supposed that the disturbance of equili-

brium depends upon a state of kathelectrotonus of one hemisphere with anelectrotonus of the other; the former hemisphere being in a state of exalted excitability and the latter in a state of diminished excitability, their action is no longer balanced, and a sensation of giddiness is the result.

The brain is not easily influenced by induction coil currents applied to the outside of the skull, though responding readily when the electrodes are applied directly to its substance, but this is only because the currents of the required strength are so painful to the skin as to be badly borne.

117. **The "refreshing action" of the galvanic current.**—Dr. G. V. Poore* has reported some remarkable experiments upon what has been called by Heidenhein "the refreshing action" of the constant current; he investigated the fatigue of muscles produced when a weight is held out steadily at arm's length, and gives an instance of a patient who was able to hold out his arm horizontally with a weight of seventeen ounces in the palm for a period of four minutes, and then complained of great pain in the muscles and fatigue, and declared his inability to go on but was relieved of his pain at once by the passage of a constant current in a descending direction along the arm. Another person was then experimented on in the same way; after holding out the weight at arm's length for seventy seconds, he felt pain and fatigue, but the application of the current at once removed both, and he continued to support the weight for five minutes and a quarter, and at the end of that time was willing to go on longer. Dr. Poore says: "similar experiments to these have

* *Electricity in Medicine and Surgery*, Dr. G. V. Poore, London, 1876.

been tried on several of the author's friends, and they all tend to show that the endurance of voluntary muscular action is enormously increased by the passage of a constant current, and the feeling of fatigue both during and after the prolonged effort is mitigated or entirely obviated."

Dr. Poore also demonstrated that the force as well as the endurance of a muscular effort could be increased by a galvanic current. Eight successive squeezes with a dynamometer, at intervals of ten seconds, gave an average of $48\frac{1}{2}$ pounds for each squeeze, but eight more squeezes with the aid of the current gave an average of $59\frac{1}{2}$ pounds, although they came ten minutes after the first series, and while there was distinct consciousness of fatigue from the first experiment.

The current used was never strong enough to produce involuntary contraction of the muscles.

118. **Trophic effects.**—Experiments were made by Dr. Beard* to determine the effect of general faradization upon the growth of some puppies, they were kept under treatment for four weeks, being treated daily with an induction coil current; at the end of the time the two puppies which had been so treated had gained in weight faster and were perceptibly bigger than the two others, which had been kept untreated as control animals; however, other experiments gave conflicting results. It is reasonable to expect that the metabolism of the tissues should be increased by the vigorous stimulation, and that a young animal should increase in size in consequence, just in the same way as massage of the muscles increases their size and activity. In the treatment of children by electricity for paralysis, a great improvement in their general health has been often

* Beard and Rockwell, *Medical and Surgical Uses of Electricity.*

noticed by myself, and general electrification applied to children with rickets does them much good.

119. **Electrical osmosis.**—The fact has been long known that a movement of electrolytic fluids comparable to osmosis takes place in the direction of flow of the current, namely, from the positive to the negative pole; and fluid can in this way be made to pass through membranes or porous diaphragms against the force of gravity; and it has been proposed to make use of this process for the introduction of drugs into the body through the skin. It is evident, however, that it is rather an elaborate method of administering a drug, and only in certain cases can it have any advantage over the methods of giving drugs by the mouth or hypodermically; besides, it would be difficult to know when the proper quantity had passed into the system. It was also hoped that in this way it would be possible to apply drugs locally, as for instance, iodide of potassium to a gumma, but this cannot be satisfactorily effected because the drug is carried off by the circulation quite as fast as it enters through the skin. Still, there is one particular object which can be well and conveniently secured in this way, namely, the introduction of cocaine to produce local anæsthesia of a portion of the skin, this can be done very simply by covering the positive electrode with a layer of absorbent cotton well moistened with ten per cent. cocaine solution, and holding it steadily to the part, which should be first well sponged with hot water; with five milliampères of current the skin should become anæsthetic in about six or seven minutes. The procedure is of value before small superficial operations, and in neuralgic affections.

Hollow cup-shaped electrodes, covered in by membrane, have been contrived to hold solutions for this

local medication, and the terms *cataphoresis* and *cataphoric medication* have been applied to the process. Erb has suggested that it might prove useful for the introduction of drugs into diseased joints; using a pair of cupped electrodes, one on either side, and reversing the direction of the current at intervals of five minutes.

120. **Death from electric shock.**—The fatal effects of powerful currents is probably due to stoppage of the action of the heart, the tracings (figs. 61, 62) show the results in some experiments upon cats under chloroform.

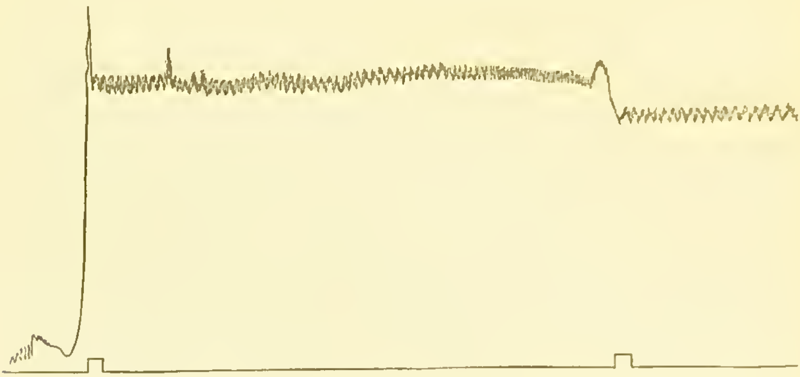

FIG 61.—Blood-pressure tracing, showing effect of electric shock through skull and through thorax of a cat.

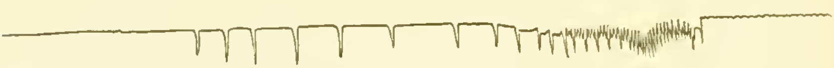

FIG. 62.—Forcible respirations at first rapid, then slowing and stopping, after electric shock.

In the first is seen the rapid fall of blood-pressure to zero after the passage of a current of half an ampère through the thorax; while a current of the same magnitude through the skull produced a trifling effect, which is seen in the first part of the same tracing. In fig. 62 is seen the secondary effect upon respiration caused by the failure of the blood supply in the respiratory centre.

To cause death the current must have a certain minimal value, and must traverse a vital organ, the heart being the most susceptible.

The views of D'Arsonval, that electricity proves fatal by primary arrest of respiration, and that the victims of shock can be resuscitated by artificial respiration, are not supported by the tracings here shown. In the absence of direct observations the minimum fatal current for human beings may be estimated at about one half to one ampère. The most common path of the discharge is from one conductor to earth through the body, but the current may also pass directly from the body to the other conductor of the system. In the first case the point of exit is generally by the feet. Burns of the skin should always be looked for at the points of entry and of exit; they may be severe or slight. When the current goes to earth through the feet these may not show signs of burning if the foot covering is damp. The severity of the burns is proportional to the duration of the discharge. Most of the fatal accidents have been with potentials above one thousand volts. The body may carry a current sufficient to produce extensive burning at the points of contact, without causing death, this may even be the case when the current has fairly traversed the trunk. In a recent accident in London two men were concerned and the current passed from the conductor to the first and from him to the second. The first man survived though the second was killed. The relative danger of alternating and direct currents is not decided; there is probably no great difference.

121. **Thermal effects.**—With the small currents used in medicine there is no appreciable heating of the tissues. A slight warmth can be felt over a nævus

during its electrolysis. In cases where death has been caused by the passage through the body of the powerful currents used for electric lighting, well marked signs of the production of heat have been observed *post-mortem* (see last paragraph).

122. **Electrical organs.**—The electrical organs of many fishes (electric eel, torpedo) may be briefly noticed in this chapter. They consist of lobes of a honeycomb-like structure, usually developing in a similar way to muscle, and supplied freely with nerves which terminate in the cells of the honeycomb in expansions something like those of muscle end-plates; irritation of their nerves causes an electrical discharge. It appears that they may have become specialised and developed from ordinary voluntary muscle, for the sake of utilising the electrical current of action, and that the structural changes are associated with the development of this portion of the muscular mechanism at the expense of its strictly motor powers. The chemical examination of the electrical organs seem to show that the products of their activity are very similar to those of active muscle, CO_2 and an acid reaction being produced.

Du Bois Reymond showed long since that muscular contraction always yields a current which can be measured by a galvanometer, and Waller has lately shown a method of demonstrating in the human subject that there is an electric current produced by the heart's beat, and that it can be led off to a galvanometer by wires from the two hands. It may be that the peculiar powers of electric fishes have grown up from the electrical current of action common to all contracting muscle, but it is difficult to trace the intermediate steps in the scale of development. The skate has an elec-

trical organ in its tail which is not able to give strong shocks, although it can deflect a galvanometer.

123. **Magnetism.**—It seems to be rather doubtful whether any physiological effect has ever been observed to be due to the action of a magnet. Lord Crawford (then Lord Lindsay) and Mr. Cromwell F. Varley, with the help of an enormous electro-magnet, belonging to the former, were unable to perceive any sensation even on placing their heads between its poles. But in discussing these experiments in an address delivered at the Midland Institute at Birmingham,* in October, 1883, Sir William Thomson came to the conclusion that it is just possible that there may be a magnetic sense, and indeed a committee of the Society for Psychical Research,† who examined a large number of persons by placing their heads near the poles of an electro-magnet, found three who were sensitive and were able to say when the current was on or off. One of these persons was examined later by Prof. W. F. Barrett,‡ who found that when he was suffering from neuralgic pain, it became intensified by the presence of a powerful magnet.

In some recent experiments conducted with very powerful electro-magnets by Dr. Peterson and Mr. Kennelly in Edison's Laboratory, the results were entirely negative as the following extracts show. The subject placed his head between the poles of a large electro-magnet, which could be excited from a dynamo-machine. They reported as follows:—

"The armature of a dynamo was removed, leaving a space between the poles of its field magnet. This field

* *Nature*, vol. xxix., p. 438.

† *Proc. Soc. Psychical Research*, part iii.

‡ *Nature*, vol. xxix., p. 476.

magnet was then excited from another dynamo, driven by steam power, and the subject introduced his head into the space between the poles. The weight of the electro-magnet was over 5000 pounds, and the intensity of the magnetic field produced within the polar cavity after removal of the armature, though not uniform, may be estimated at a mean of 2500 C.G.S. lines to the square centimetre. A long board was placed upon the base plate leading into this polar cavity, and the subject experimented upon lay on his back upon the board with his head and shoulders in the cavity between the poles, and exposed thus to the full influence of the magnetic field. A switch so nearly silent in action as to be inaudible to the subject was arranged to close and open the exciting current circuit through the field coils. On closing the switch nearly the full magnetic intensity would be active and permeating the head within practically one second. Similarly on opening the switch, almost the whole intensity would disappear in about one second."

"Five men, ourselves among the number, were subjected to trial. One case described will describe all."

"The subject lay back upon the board and concentrated his attention upon his sensations. His right wrist was extended and was grasped by one observer, who took sphygmographic tracings of the pulse. A second observer placed a hand on his chest to observe any irregularity that might occur in respiration. A third observer, in view of these two, but unseen by the subject of the experiment, opened and closed the switch that excited and released the field, signalling to the first two observers as he did so. The strong magnetic influence was therefore turned on or off at will, and without the knowledge of the subject. Several sphygmographic

tracings were taken in each of our subjects, and in one the knee-jerk was tested continuously."

"The sphygmographic tracings taken during the *séance* show no change in regularity, in spite of the making and breaking of the enormous magnetic influence during its registration. The respirations were not changed in the least. The knee-jerk also presented absolutely no change. As to common sensations, there were none that could be attributed to the magnetic influence, and the subject could not discover when or whether the field had been excited. The testimony of all five subjects was alike."

"No change could be seen in the circulation in the web of a frog's foot when this was placed between the poles of a large electro-magnet, and no effect was perceptible in a dog which had been confined for five hours in a strong magnetic field."

Experiments were also tried with another magnetic arrangement, in which the magnetism was reversed 280 times a second, as follows:—

"A large coil of stout, cotton-covered copper wire, about 30 ctm. high, and 25 ctm. internal diameter, composed of nearly 2000 turns, and weighing about 70 kilogrammes, was supported horizontally in such a manner that the head of the subject experimented upon could be freely introduced within the coil, and subjected to the electro-magnetic field created there by passing a current through the wire. The resistance of the coil was 10 ohms, and its inductance 0·73 henry. An alternating electromotive force of 1200 volts, making 140 cycles or 280 alternations to the second, was connected with this coil, the current supplied being 1·85 ampères. The magnetic field in the coil would thus be reversed 280 times to the second. Each of the authors acted as

subjects in the experiments, permitting the 1200 volt alternating current to be made and broken frequently in the huge magnetic coil surrounding his head. No effect whatever was experienced. The coil itself hummed with the current, and a strip of sheet iron held in the cavity of the coil, but not touching it, vibrated perceptibly in the hand and gave a distinct, loud sound, which was determined to be middle C of the musical scale."

"The authors conclude that the human organism is in no wise appreciably affected by the most powerful magnets known to modern science; that neither direct nor reversed magnetism exerts any perceptible influence upon the iron contained in the blood, upon the circulation, upon ciliary or protoplasmic movements, upon sensory or motor nerves, or upon the brain."*

It need hardly be pointed out that the phenomena of so-called "animal magnetism" have absolutely nothing to do with magnetism whatever. Moreover, the ordinary magnets used in medicine, and credited with wonderful powers, have a purely suggestive or psychic effect, and would in all probability be quite as useful if made of wood.

* Read before the American Electro-therapeutical Association, 1892, reprinted, with illustrations, in *Electrical Review*, August 18th, 1893.

CHAPTER VII.

DIAGNOSIS.

Method of procedure. The motor points. Relation of spinal nerve roots to muscles. Practical testing. Electro-diagnosis charts. Morbid changes in the electrical reactions. Quantitative changes. The reaction of degeneration. Course of the reaction of degeneration. Partial reaction of degeneration. Anomalous reactions. Sensory nerves. Nerves of special sense. The auditory nerve.

124. **Method of procedure.**—When a patient with any disorder of the nervous system presents himself for treatment, it is usually necessary to investigate the electrical reactions of his nerves and muscles, for much may often be learned from this procedure.

It will be found that a considerable amount of care and of time must be devoted to this investigation; for it is not so easy to arrive at clear results as one might be led to expect from the perusal of a chapter on electrical testing. Both the interrupted and the continuous currents must be employed. To simplify matters the unipolar method of excitation should be adopted, the indifferent electrode being placed upon a distant part of the body, as upon the sternum, or the sacrum or the upper part of the back, according to convenience, or the requirements of the particular case. The indifferent electrode (fig. 38) should be well moistened with warm water (salt solution is not necessary and it corrodes the electrodes) and should be in good contact with the surface of the skin. The other or exciting electrode must

be small for the sake of localising the current to the particular spot required, a suitable size is one of about $\frac{4}{5}$ inch (20 mm.) in diameter; it should have a closing key (figs. 35, 36), and it must be applied with uniform pressure. It is sometimes useful to fasten the indifferent electrode over the trunk of the nerve supplying the muscles to be tested, in that way the effect of the stimulation can be rather more limited to the muscles under examination. A convenient form of indifferent electrode in such a case is one fastened to a strap or garter of webbing or flannel with a buckle to fix it firmly in place.

The case to be examined may be one in which the disease is limited to one side of the body, or it may affect both sides. The first case is the simplest because of the advantage of having a sound side for purposes of comparison. If both sides are involved in the disease it becomes more difficult to recognize small changes in the electrical reactions, and one has to fall back for guidance upon previous experience, or help may be found in a comparison of one's own corresponding muscles with those of the patient, or by the use of the galvanometer.

It has been shown by Erb that it is usual for the two sides of a patient's body to be remarkably equal in their response to stimulation, provided always that the skin resistance of the two sides is the same or nearly so. This skin resistance can be measured by the galvanometer and allowed for. For the most part one does not expect to find much difference in the skin resistance of the two sides, but accidentally there may be a difference and the electromotive force of the battery must, if necessary, be altered to suit it, by increasing or decreasing the number of cells in the circuit. For in-

stance, if the galvanometer reads 2 milliampères for the minimal contraction when the electrode is applied to the right ulnar nerve, the stimulation of the left ulnar nerve should also yield a minimal contraction when the galvanometer reads 2 milliampères, and this whether the number of cells of the battery required to drive this current through the circuit be the same on both sides or not. By adjusting the number of cells in the battery so as to give equal currents, the two sides may be compared; and a guide as to their relative resistances is afforded by comparing the number of cells needed to give an equal current on the two sides.

The introduction of a galvanometer which will give readings with the induction coil current is likely to simplify the process of electrical testing very greatly (see p. 101). When such an instrument is not at hand the resistances may be taken by the aid of the battery current and an ordinary milliampère-meter; and the results obtained may be roughly allowed for in the induction coil testing. Comparisons based upon the distances apart of the primary and secondary of a sledge coil may be used, but they are apt to be untrustworthy, owing to disturbing influences which are likely to vitiate the results, thus the battery driving the coil may grow weaker and weaker from day to day, or even during the progress of a test.

Generally speaking the kathodal closing contraction should appear with a current of two milliampères, if the active electrode be correctly placed over a superficial motor nerve trunk in an average person, with the size of electrode already specified. If the patient be stout, and if an electrode larger than the standard be used, then the current necessary to produce the minimal stimulation will be larger, the reason in both cases

being that the curreut is less effectively concentrated upon the nerve.

125. **The motor points.**—To continue the examination of the patient; the tests must be applied to the motor nerves, the muscles, and the cutaneous sensory nerves in the parts affected, and they must be compared with the same parts of the opposite and healthy side when this is possible.

To do this it is absolutely essential to know thoroughly the points where the nerve trunks are most accessible, the motor points of the muscles, and the distribution of the cutaneous nerves.

This requires a certain amount of anatomical knowledge and many diagrams have been prepared as a guide and help to the memory; most of them are based upon Von Ziemssen's plates. In the preparation of these plates the stimulation of the nerve trunks, and of the motor points of the muscles was carried out as follows:—

The indifferent electrode being placed upon the sternum, a fine pointed exciting electrode of metal covered with wash leather was applied successively to different parts of the muscle under examination, until a position was found (the motor point) where a maximum effect was produced, this was marked with coloured chalk or with nitrate of silver; all the muscles were in turn examined and their motor points marked, the limb with the marks was then photographed. Von Ziemssen verified the positions by following the course of the nerves in the dissecting room, and finding where they entered the muscles, and the relation of such points of entry to the surface of the body, he also excited the muscles of bodies recently dead, before the muscular irritability had disappeared, and marking the spots on the surface

of the skin where contraction was most readily produced, he then cut down and found that the motor point corresponded closely to the point where the nerve entered the muscle.

It should be borne in mind that the motor points are not quite constant for different individuals, their exact place varying a little in different cases, but not so greatly as to diminish the value of knowing their positions. In actual practice the best position of the electrode can be readily found by experiment, by moving it about in the neighbourhood of the usual position of the motor point of any particular muscle until the contraction shows that the exact spot has been touched. The ease with which the motor points can be found depends a good deal upon the amount of subcutaneous fat present, and the examination of the deeper muscles is much more difficult than of the superficial layer, indeed in the case of some of the deep muscles it is almost impossible to produce satisfactory evidence of a contraction limited to the muscle sought, for the diffusion of the current will throw into action the neighbouring superficial muscles and so obscure the result. It is very important to place the patient's limb in a good position, so that any muscular movement looked for may be readily seen; the muscles must be lax, the limb should be supported by the hand of the operator, and not lying flat upon the table or couch. It is best to begin with a current which is strong enough to throw the muscles into contraction and to apply it only for a very brief moment at a time, in this way the patient will be less alarmed, and the process of testing will be sooner over. It is well always to try the strength of the current on oneself before touching the patient.

It is assumed that the action of the individual mus-

cles is known, so that when a contraction is produced, it can be referred to its proper muscle. The actions of the muscles were elaborately studied by Duchenne, as one of the outcomes of his methods of treatment by localised application of the electrical current to paralysed muscles, and he has described them at great length in his *Physiologie des Mouvements.* Besides watching for and seeing the movement produced by the contracting muscle, one may often feel a weak contraction by placing the hand over the tendons lightly, or one may see or feel movements of the fibres of the muscle itself when they are too feeble to move the bone to which the muscle is attached.

The subjoined table of the points at which certain nerves may be conveniently stimulated will be of service, and Plates I. to VI., which show the motor points, must be continually referred to until they are known by heart. The areas of skin which are served by the several cutaneous nerves must also be thoroughly mastered; Heiberg's *Atlas of the Cutaneous Nerves*, translated by Dr. Wagstaffe,* has some useful coloured outlines of these areas of distribution. Prof. Flower's *Atlas* may also be referred to. (See Plates VII. to IX., after Flower and Ranney).

Points favourable for the electrisation of nerves:—

In the upper limb:—

1. *The median*, along the inner border of biceps, and at the bend of the elbow.
2. *The ulnar*, in the groove between the internal condyle and the olecranon.
3. *The musculo-spiral*, at the point where it emerges from the triceps; namely, on the outer side of the

* Baillière, Tindall and Cox, 1885.

upper arm about the junction of its middle and lower thirds.

4. *The musculo-cutaneous*, between the biceps and coraco-brachialis.
5. *The long thoracic* (serratus magnus) on the inner wall of the axilla.
6. "At a spot one inch above the clavicle, and a little externally to the posterior border of the sterno-mastoid, immediately in front of the transverse process of the sixth cervical vertebra, a simultaneous contraction can be produced in the deltoid, biceps, coraco-brachialis, brachialis anticus and supinator longus." This point has been called the *supra-clavicular point* of Erb.

In the lower limb :—

7. *The anterior crural*, in the fold of the groin just outside the femoral artery.
8. *The sciatic*, in the pelvis, through the coats of the rectum; or just below the gluteal fold at the back of the thigh.
9. *The peroneal* or *external popliteal* just above the head of the fibula, beside the biceps tendon.
10. *The internal popliteal nerve*, in the popliteal space, and to the inner side of the tendo Achillis.

In the face :—

11. *The facial*, through the cartilage of the lower surface of the meatus auditorius. Its chief ramifications can be reached where they emerge from the parotid gland. Erb chooses for stimulation three main branches of the facial: (*a*) for muscles above the palpebral aperture; (*b*) for those in front of the upper jaw, between the orbit and the mouth; (*c*) for muscles of the lower jaw. He tests each of these in two places, first at points just in front

of the ear, and secondly for (*a*) at the temple, for (*b*) at anterior extremity of zygomatic bone near its lower border, for (*c*) at the middle of the inferior border of the horizontal ramus of the lower jaw.

12. *The fifth*, at the supra-orbital foramen, at the infra-orbital foramen, at the foramen mentale, on the side of the tongue

In the neck :—

13. *The spinal accessory*, at the top of the supra-clavicular triangle, where the nerve pierces the sterno-mastoid.
14. *The phrenic*, on the outer edge of the lower part of the sterno-mastoid.
15. *The hypoglossal*, along the upper border of the great cornu of the hyoid bone.
16. *The recurrent laryngeal*, along the outer border of the trachea.
17. *The pneumogastric* and *glosso-pharyngeal* along the track of the carotid artery just below the angle of the jaw.

126. **Relation of spinal nerve roots to muscles.** —Frequently it happens that paralysis affects a group of muscles; in these cases much light may be thrown upon the diagnosis if it is possible to trace back the nerve supply of the affected muscles to their spinal roots. This is not always easy, particularly when the nerve trunks pass through a plexus like the brachial plexus on their way from the cord to the muscles; for example, the distribution of a paralysis affecting some of the muscles of the hand might enable us to distinguish between a lesion of the trunk of the median nerve on the one hand, and a lesion of the eighth cervical and first dorsal roots on the other; in the latter case the whole of the thenar and hypothenar eminences and all

the lumbricales and interossei would be involved, in the former case many of these muscles would escape, namely, the hypothenar, the interossei, the two inner lumbricales, the adductor pollicis, and the inner half of the flexor brevis, all of which are supplied by the ulnar nerve.

A paper published in *Brain*, 1881, by Dr. Ferrier, gives a tabular statement of the more important spinal nerve roots, with the muscles supplied by each. As it is likely to be of great value in electrical diagnosis we reproduce it here, as modified by Dr. De Watteville, *Lancet*, July 14th, 1883.

Nerve roots :—

4th cervical.—Deltoid, rhomboids, spinati, biceps; brachialis anticus, supinator longus; extensors of hand.

5th cervical.—Deltoid (clavicular portion), biceps; brachialis anticus, serratus magnus, supinator longus; extensors of hand.

6th cervical.—Latissimus dorsi, pectoralis major, serratus magnus, pronators, triceps.

7th cervical.—Teres minor, latissimus dorsi, subscapularis, pectoralis minor, flexors of hand, triceps.

8th cervical.—Flexors of wrist and fingers, muscles of hand, extensors of wrist and fingers, triceps.

1st dorsal.—Muscles of hand (thenar, hypothenar, interossei).

3rd lumbar.—Ilio-psoas, sartorius, adductors, extensor cruris.

4th lumbar.—Extensor femoris et cruris; peroneus longus; adductors.

5th lumbar.—Flexors and extensors of toes—tibial, sural, and peroneal muscles, extensors and rotators of thigh, hamstrings.

1st sacral.—Calf, hamstrings, long flexor of great toe, intrinsic muscles of foot.

2nd sacral.—Intrinsic muscles of foot.

Reference to the paper of Dr. Ferrier will show that in his table the function of each nerve root is expressed in terms of the movements produced, and not in terms of the muscles concerned in producing the movements.

Dr. Herringham* has also tabulated as follows the results of numerous dissections of the brachial plexus in new-born infants.

Usual nerve supply :—

3rd, 4th and 5th cervical.—Levator anguli scapulæ.

5th.—Rhomboids.

5th or 5th and 6th cervical.—Supraspinatus, infraspinatus, teres minor.

5th and 6th cervical.—Subscapularis, deltoid, biceps, brachialis anticus.

6th cervical.—Teres major, pronator radii teres, flexor carpi radialis. Supinator longus and brevis. Superficial thenar muscles.

5th, 6th and 7th cervical.—Serratus magnus.

6th or 7th cervical.—Extensores carpi radiales.

7th cervical.—Coracobrachialis, latissimus dorsi, extensors at back of forearm, outer head of triceps.

7th and 8th cervical.—Inner head of triceps.

7th, 8th and 1st dorsal.—Flexor sublimis and profundus, flexor carpi ulnaris, flexor longus pollicis, and pronator quadratus.

8th cervical.—Long head of triceps, hypothenar muscles, interossei, deep thenar muscles.

The *pectoralis major* from 6th, 7th, 8th and 1st dorsal.

The *pectoralis minor* from 7th, 8th and 1st dorsal.

Dr. Gowers† also gives a table of the "approximate

* *Proc. Roy. Soc.*, March, 1886.

† *Diseases of the Nervous System*, vol. i., 1886.

relation" of the spinal nerve roots to the various motor, sensory and reflex functions of the spinal cord.

127. **Practical testing.**—When a fair degree of proficiency in finding the motor points has been acquired, the chief difficulties of the investigation of the reactions of a patient's muscles will disappear. Nothing is so useful as to practice frequently upon oneself, and the dislike which many people have to applying currents to their own persons is much to be deprecated. A current which is strong enough to provoke contraction in the muscles is not really painful, and it certainly inspires confidence in the patient if he sees the physician begin by applying the current to his own muscles. Sometimes the current applied is not strong enough, and thus the mistake may be made of supposing that muscles do not respond when really they would do so readily if a sufficiently strong current were used.

The method of testing is as follows:—Place the indifferent electrode, well moistened, in position, take the testing electrode with key in the right hand, and hold the patient's limb in the left, then set the induction coil in action and apply the testing electrode to the skin of the left hand, the current will pass through from operator to patient, and the sensation felt will be an indication of the strength of the current. Then after well moistening the patient's skin over the various motor points, apply the electrode and note the effect. If the muscles contract it is well, if not the strength of current must be carefully increased. There is no need to push the strength of the testing current too far. The motor nerve trunks of the part may also be tried, if they can conveniently be reached, and the effect may be noted. Then passing to the battery current, commence with

about sixteen cells for the limbs, or half that number for the face, and apply the electrode, which should be made the kathode. Note whether a closing contraction is visible or not, if not increase the number of cells in circuit until it appears, and take readings of the galvanometer; when the first closing contraction becomes visible note the effect of moving the electrode, and find the most effective spot for stimulating the muscle, then compare the A.C.C. with K.C.C., and take especial notice of the nature of the contraction, to see whether it be quick or sluggish, compare the contractions obtained by direct stimulation of the muscle with the effects of stimulating the nerve trunks. Lastly, test sensation with the induction coil current, and note the results upon a table like that given in the accompanying leaf.

Compare the reactions of the healthy side with those of the affected side.

When the affected parts can be compared with the corresponding region on the opposite and sound side of the body, it is not difficult to perceive changes in the electrical reactions. When the disease is bilateral this is not so simple, and one must depend to a certain extent upon previous experience, and upon comparisons with one's own reactions. Erb has propounded a method of procedure for these cases, which is as follows:—

He says: "in order to eliminate the necessity of comparison with other individuals, and to find a standard of comparison on the same person, I have tried a wider method of exploration. It consists in determining the excitability of nerves in different regions of the body, and afterwards comparing the results and fixing the relative value in different individuals. We find a

REPORT OF ELECTRICAL REACTIONS.

Name—T. B. S. *Age*—32 *Date*—Oct. 4th, 1894.

Region examined—Left arm and forearm. *Diagnosis*—Neuritis of musculo-spiral N.

Muscles.	Induction Coil.	Battery.	Excitability.	Remarks.
Triceps.	Natural.	Natural.	Natural.	A tender point over musculo-spiral trunk in middle of upper arm.
Supinator longus.	Decreased but not lost.	Sluggish.	Increased.	
Ext. carpi rad. longior.	"	"	"	Injury three weeks before.
" " " *brevior.*	"	"	"	Partial reaction of degeneration in all these muscles except triceps.
Ext. carpi ulnaris.	"	"	"	
Ext. comm. digit.	"	"	"	*Supinator brevis* not tested.
Ext. ossis metacarpi poll.	"	"	"	
" *primi internod.* "	"	"	"	Sensation impaired over extensor aspect of fore-arm.
" *secundi internod.* "	"	"	"	Voluntary power much impaired. Wrist drop.
" *indicis.*	"	"	"	
" *minimi digiti.*	"	"	"	The other muscles of the limb quite normal.

Treatment—Electricity (induction coil). *Prognosis*—Favourable.

fairly constant correlation between the four pairs of nerves we have chosen, so that too considerable deviations of one of them with reference to the relative value may be considered as pathological." Hence the following method:—"In testing we must always choose these four nerves—the *frontal* nerve or branch of the facial nerve supplying the *frontalis* muscle, the *accessory* nerve, the *ulnar* nerve at the elbow, and the *peroneal* nerve. On each of these nerves we must determine with great care with a fine electrode, on the most excitable spot, the distance of the coils at which the minimum faradic contraction occurs, this is done by marking the number at which the weak but visible contraction is obtained with the negative pole of the secondary coil. Then by means of the galvanic current and with a middle sized electrode, moistened with hot water every time it is applied, the galvanometric deviation is determined with a definite number of cells (ten or twelve). The positive pole remains fixed upon the sternum, and the negative is applied to all the spots at which the excitation is made. The numbers thus found are tabulated."

"We thus obtain two series of numbers, the one representing the relative faradic excitability of the four nerves, the other the relative state of the resistance at the corresponding points on each side of the body. I have already pointed out how the results of the second series assist the conclusions to be drawn from the first." "In this manner* we learn that the numbers obtained for either side of the body coincide almost exactly, further, all four pairs of nerves are excited by minimum currents of sufficiently comparable strength; the relation between the ulnars and peroneals in this

* Erb, *Electro-therapeutics*, p. 144.

respect is of special import, they require almost equal distances of coils, while the frontals often respond to a distance slightly less (a slightly stronger current) and the accessories to one a little greater (a slightly weaker current)." "I think it well to direct your attention here to some of the difficulties and sources of error which you may have to encounter. In the first place you must find the place where the nerve is most excitable, and then determine the weakest current which will excite it. Much skill and patience are required for this, it is wonderful to see how slight a movement of the exciting electrode will produce a wholly different effect. Special difficulties arise in connection with the ulnar and peroneal nerves; the situation in which the former is most excitable is about three centimetres above the internal condyle, at the inner border of the triceps; in the case of the peroneal it is three or four centimetres above the head of the fibula, beside the tendon of the biceps, and can be reached with the electrode only after much searching."

By the employment of Giltay's galvanometer (§ 70), the examination of these nerves can be more satisfactorily carried on, for the comparison of the readings indicated by that instrument gives an estimate of the irritability of the nerves more directly than by the method of the scale on a sledge coil, and no correction is necessary for possible differences of resistance on the two sides of the body.

For recording the results of electrical testing many forms of chart have been suggested; the one used above has the advantage of being simple.

128. **Morbid changes in the electrical reactions.**—The changes in the electrical reactions which are found in disease may be classed as follows:—

A. *Motor.*

1. Increased excitability	(*a*) To coil (*b*) To battery current	Quantitative changes.
2. Diminished excitability	(*a*) To coil (*b*) To battery current	
3. Reaction of degeneration	(*a*) Complete (*b*) Partial	Qualitative changes.
4. Other motor anomalies		

B. *Sensory.*

1. Increased excitability.
2. Diminished excitability.

129. **Quantitative changes.**—(*a*). *Increased or decreased irritability to coil current.*—Before forming a diagnosis of increase or decrease of irritability it is necessary to keep in mind the importance of measuring the resistance of the patient at the same time, because without the galvanometer it is not easy to know how much of the result depends upon altered resistance and how much on altered excitability.

In unilateral disease increased or decreased excitability is shown by differences in the behaviour of the two sides. If the normal side be first tested and the distance in millimetres of secondary from primary be taken with the minimal stimulus, an increase of excitability will be shown on the affected side if the minimal contraction shows itself with a greater distance between the coils. If both sides are affected, then an increased excitability is inferred if the minimal stimulus is seen with the secondary further from the primary than the distance which the operator has taught himself to recognise as usual in healthy people; if the galvanometer is used its readings at point of minimal contraction give a direct measure of the irritability; or by Erb's method the

comparison of frontal, accessory, ulnar and peroneal nerves may show an order of excitability unlike that of health ; it is not often that all four of these nerves are involved for both sides, situated as they are in parts of the body remote from one another.

(*b*) *Increased or decreased excitability to battery current.*—Simple increase of excitability is shown by the development of KCC with a smaller galvanometer deflection than usual, by the ready production of duration tetanus, and generally by the easier production of all the contractions.

Simple diminution of excitability is shown by increased difficulty in the production of all the contractions. A stage may be reached when they can be obtained only with strong currents, and finally all reaction may disappear ; excitability is then said to be lost or abolished.

Increased excitability of the nerves and muscles is not very common, when it does occur it represents phases of irritation, and therefore it may be seen in the early stages of several disorders (such as tabes, chronic myelitis, hemiplegia) where at a later period the reactions become diminished.

Simple diminished excitability occurs in many old standing nervous diseases, in myopathic muscular atrophies, in some cases of peripheral neuritis (alcoholic and other) in paralysis or wasting after joint diseases. Its recognition is important, and particularly so when the diagnosis rests between it and the reaction of degeneration.

130. **Qualitative changes—The reaction of degeneration.**—This term was introduced to signify the altered electrical reactions which occur in nerves and muscles under certain special pathological conditions;

the peculiar feature being that the change is not only a quantitative one, but also a qualitative one; that is to say, there is an alteration in the quality of the response which the degenerate muscles make to the battery current. KCC often becomes relatively less easily elicited than ACC, though this is not invariably the case, and the contraction provoked is a slow and sluggish one, differing greatly from the very rapid contraction given by a normal healthy muscle.

This reaction of degeneration (usually symbolised by the abbreviation RD) is of very great importance. Its discovery and development arose from an observation of Baierlacher in 1859, that the muscles in a case of facial paralysis did not respond to the coil, but reacted with unusual force to the battery current, and to Erb's careful study of the symptom then first made known, we owe the most important fact connected with electricity in medical diagnosis.

The investigation of the reaction of degeneration has been pursued both clinically and experimentally, and its value consists in the fact that when it is present we can diagnose a break in the nervous link which connects the end plate of the muscle with its "nucleus of origin" in the grey matter of the anterior cornu of the spinal cord; the lesion therefore must either be in the grey matter of the anterior horn in the cells from which the nerve fibre starts, or in the course of the nerve fibre from there to the muscle. The reaction of degeneration does not follow lesions which are above the spinal ganglion cell whence the nerve fibre springs (see table, § 133), nor does it follow affections which are confined to the muscle fibres proper (idiopathic muscular atrophies).

In RD the irritability of the nerve disappears en-

tirely, and therefore stimulation of it has no effect, the muscle on the other hand retains its irritability to the battery but not to the coil current, that is to say its irritability is still present for certain stimuli, and its contraction wave can be transmitted from muscle fibre to muscle fibre, much as it is in a curarised muscle. It dses not react to the interrupted current of an induction coil, perhaps because the individual shocks are too brief, but it reacts to the stimulus of a smart blow and to a battery current slowly made and interrupted. If the battery current be made and broken rapidly by an automatic vibrator, the muscle will not respond to it. A curarised muscle will still react to coil currents, though not so readily as a normal muscle, therefore the total loss of "faradic" irritability in a muscle showing the reaction of degeneration signifies something more than a torpor of the intramuscular nerve endings, it means that a trophic change has occurred in the muscle protoplasm, and further evidence of the change is seen in the frequent production of ACC more easily than KCC. This alteration of the relative effect of the poles, is not an important part of the reaction of degeneration, for it is not constantly present. Another important alteration is that the irritability of the muscle to the battery current may be greater than in health, strong contractions being set up in the affected muscles by currents which are too weak to produce any visible movement in healthy parts.

It is only in fairly recent cases that the phase of exaltation of muscular irritability is manifested, and in most cases of RD, that is, of course, if recovery does not set in, the later stages show a progressive loss of irritability of the muscle.

Erb's definition of the reaction of degeneration is the

following:—"It is characterised by the diminution and loss of faradic excitability in both nerves and muscles, whilst the galvanic excitability of the latter remains unimpaired, is sometimes notably increased and always undergoes definite qualitative modifications."

131. **The course of the reaction of degeneration.**—At first for two or three days after the onset of the lesion there will be in the *nerve* a progressive lowering of all electrical excitability, and after this the irritability of the nerve will be completely abolished and will remain so unless recovery takes place; in that case the return of motor power may precede the return of electrical irritability.

In the *muscle* the reaction to coil currents runs the same course as in the nerve. To battery currents, on the other hand, there is at first a progressive lowering of excitability, but by the end of a week this is replaced by an increase of excitability to a point much above the normal, with sluggishness of contraction and often with ACC > KCC; after a period of three, six, or eight weeks, diminution of excitability sets in, and the diminution is progressive until at last it may disappear entirely.

In cases which recover it often happens that the power of voluntary movement will return some little time before the response to electrical stimuli, but in other cases both may return simultaneously.

When a nerve has been completely divided the changes which occur are as follows:—

1. A sudden loss of voluntary power in the muscles supplied by the divided nerve.

2. Arrested conductivity of the nerve—therefore abolition of excitability in the muscles supplied from below the wound, when both electrodes are placed on or near the nerve trunk above the seat of injury.

3. For two or three days, sometimes only for forty-eight hours, contractility to coil currents remains present in the muscles when the electrodes are applied on the distal side of the section or on the bodies of the muscles. The disappearance of this reaction shows degeneration and loss of irritability extending down the intra-muscular nerve fibres to the end plates.

4. Increased "galvanic" irritability accompanied by a relative increase of anodal excitability. The anodal closing contraction (ACC) often approaching in amplitude and ultimately exceeding (about the sixth or seventh day) the cathodal closing contraction (KCC). The electrodes are applied, one on an indifferent part of the body, and the other on the muscle, and the direction of the current is alternated on purpose to compare the amplitude of the contractions produced. The appearance of ACC before KCC is not a constant symptom in RD, ACC may be equal to KCC or it may be less in cases of typical RD.

5. During this period the muscular fibrillæ are losing their striated appearance and are undergoing some change in their constitution. The nuclei then increase in number and there is a proliferation of the connective tissue between the fibrils and a wasting of the muscle fibres. This ultimately will lead to a fatty condition in the muscle.

6. As the muscle degenerates its irritability steadily declines. The final disappearance of all irritability may not take place for many weeks or months or years.

7. If union of the divided nerve takes place, voluntary movement in the muscles again becomes possible; muscular regeneration commences; the electrical reactions gradually return and the irritability again very

gradually rises to its former condition as it existed before the nerve was divided.

Such is a review of the typical electrical reactions of nerve and muscle after complete severance of a nerve, and these reactions modified in various ways, by the amount of destruction to the motor centres or cells, or the conducting nerve fibres, are characteristic of the several nervous diseases where qualitative changes in the electrical reactions are to be observed.

Professor Erb is careful to remind his readers that various deviations from the typical form of the reaction of degeneration may be met with. He says: "You must not expect to find in every pathological condition so great a uniformity in the course of these modifications as is to be met with in experiment, or in a simple traumatic lesion of the nerves, this does not often occur in disease, where many deviations may be caused by the nature of the injury, different affections of trophic influences, occasional improvement, or new elements of disturbance following one upon another; and one is not warranted in concluding from some irregularity, such as presents itself in long-standing cases, that one has discovered some fresh anomaly. The time at which repair takes place determines great differences in the general manifestation of the reaction of degeneration. If this happens early the nerve may be endowed with galvanic and faradic excitability while the changes in the muscle are at their height, these latter cannot be reformed so quickly, and require for the purpose some lapse of time. It may happen then, that when the nerve is excited the muscle responds with normal contractions, but still when stimulated directly exhibits the reaction of degeneration. But if repair sets in very late, it may be that the muscular excitability is already greatly

diminished when the excitability of the nerve begins to be slowly restored. There is, therefore, an indefinite number of special cases, which nevertheless may be mastered by carefully attending to the conditions of time and other circumstances."

132. **Partial reaction of degeneration.**—Under this name Erb has brought together and grouped certain deviations from the normal type; in these there is simple diminution of irritability in both nerve and muscle for coil currents combined with sluggishness of contraction of the muscle for battery currents.

Muscles having the partial reaction of degeneration may exist in a limb side by side with others showing the complete form, and other muscles may show other degrees of transition between the normal state and partial or complete degeneration, but the existence of such a condition as that in which the muscles show a reaction of degeneration, though connected to the central nervous system by a nerve still functional, or at least capable of conducting impulses to the muscle, makes it more than ever difficult to understand the exact meaning of the muscular changes which give rise to the phenomena of the reaction of degeneration. Erb especially insists that although the partial form could be simulated by the particular case of commencing recovery from complete reaction of degeneration, yet the two states are different; for the partial reaction of degeneration may be present at the commencement of an attack, and may be followed at a later period by the complete form in the same nervous and muscular structures.

"Partial RD" is not uncommon, and this makes it important in testing to confirm the results of the coil test by the application of the battery current test. If partial RD be present there is usually a perceptible alteration in the coil reactions, but this may be overlooked.

133. **Conditions which lead to the reaction of degeneration.**—Briefly speaking, RD follows upon damage in that region of the motor path to which Dr. Gowers has given the name of the "lower segment," that is to say, that part of the course of a motor fibre which commences at the motor ganglion cell of the nucleus of origin or of the anterior cornu, and is continued down as a nerve fibre to the motor end-plate beneath the sarcolemma of its muscle.* It does not follow damage limited to the "upper segment." RD is found after division destruction or injury of motor nerve trunks, and after disease or injury affecting the ganglion cells of the anterior cornu of the cord, or the corresponding nuclei of origin in the case of the cranial nerves. Under one or other of these morbid states can be grouped pressure palsies of all kinds, different forms of peripheral neuritis, division or laceration of nerves, poliomyelitis anterior both acute and chronic, muscular atrophies from disease in the spinal cord or in the nerves (but not atrophies of muscular origin), also lead poisoning, acute and chronic myelitis, and diphtheritic paralysis. The reaction of degeneration

* "It is worth while to consider for a moment the whole motor path, from the cortex of the brain to the muscles; we may consider it as composed of two segments, an upper and lower, each consist of a ganglion cell above, a nerve fibre, and the terminal ramification of the latter; the upper "cerebro-spinal" segment consist of the cortical ganglion cell, and the pyramidal fibre which proceeds from the cell, passes through the brain and cord, and ends by dividing in the spongy substance of the anterior cornu. The lower "spino-muscular" segment consists of the spinal ganglion cell, and the fibre proceeding from this, passing from the anterior root and nerve trunk to the muscle, where it divides and ramifies on the muscular fibre......... It will be found that this conception of the motor path conduces to clearer ideas of many phenomena of disease." Gowers' *Diseases of Nervous System*, 1886. vol. i., p. 116.

is not found in the paralysis of cerebral disease (except when the implication of the nuclei of origin or of the nerve trunks of the cranial motor nerves produces a reaction of degeneration in the muscles which they supply) nor does it occur in diseases limited to the white matter of the cord, nor in hysterical paralysis.

Dr. de Watteville has drawn up the following table for a guide to the position of a lesion so far as it is indicated by the electrical reactions.

REACTIONS :—

- A. Normal
  - 1. Healthy (shamming).
  - 2. Functional disturbance of
  - 3. Organic ,,
    - Cortex.
    - Corpus striatum.
    - Peduncles.
    - Pons.
    - Lateral columns.
    - Peripheral nerves (very slight disease).
    - Muscles.
- B. Abnormal
  - Quantitative alterations.
    - Augmented irritability.
      - Irritative process in
        - Brain.
        - Lateral column.
      - Hyper-excitability in
        - Cornua.
        - Nerve-muscle.
    - Diminished irritability.
      - Alterations in nerve-muscle of spinal origin.
      - Alterations in nerve-muscle of idiopathic origin.
      - Alterations in nerve-muscle of post-regenerative origin.
  - Quantitative and Qualitative.
    - Complete reaction of degeneration.
      - Destruction of anterior horn.
      - Disease of multipolar cells.
      - ,, trophic centres of nerve-muscle.
      - Severe lesion of nerve trunk.
    - Partial reaction of degeneration.
      - Slight disease of multipolar cells.
      - Disease of trophic centres of muscle.
      - Slight disease of nerve trunk.

134. **Prognosis in the reaction of degeneration.** —"Other things"—that is the cause and nature of the disease—"being the same, the lesion is serious, the probable duration of the disease longer, the definite prospect of a cure more remote in proportion as the reaction of degeneration is developed and complete, and in proportion to the stage which it has reached" (Erb).

He instances the value of the symptom in the prog-

nosis of simple facial palsy, distinguishing three forms. (1) *Mild*, electrical reactions normal, prognosis favourable, probable duration three weeks. (2) *Intermediate*, partial RD, duration one or two months. (3) *Serious*, complete RD, prognosis bad, duration three, six, nine months or longer.

At the same time he emphasizes the importance of the saving clause with which the quotation opens, insisting that it is not permitted to reason alike in all paralyses, without giving due weight to the importance of the lesion producing them, for instance the prospects of a case of facial palsy from caries of the petrous portion of the temporal bone cannot be expected to resemble those where the mischief has been set up by a mere exposure to cold; and electrical reactions which are a guide to prognosis in cases of the latter type must not be forced into a similar interpretation for the former. There is an important remark of Dr. de Watteville's from the paper quoted above:—"It may not be unnecessary to guard the student against the error of looking upon the occurrence of alterations in the response of nerves and muscles as in itself indicative of irreparable mischief. On the contrary, RD is often of far more favourable prognosis than normal reactions, which we have already found to be consistent with absolutely incurable lesions, involving complete paralysis. Intractable spasms, tremors, or convulsions again are never accompanied by any notable disturbance, quantitative nor qualitative, of the electrical reactions."

135. **Anomalous electrical reactions.**—(*a*). *RD or partial RD occurs in muscles which are not paralysed.* This condition of affairs was first described by Erb, but it has since been noticed by Bernhardt, Kast, Buzzard, Hughes Bennett and others. Many of the cases re-

corded have been in people showing signs of lead poisoning, though not all were such, and for the most part the nerves responded to testing, though not quite so well as in health, while the muscles showed the alterations of the reactions of degeneration (partial RD); in others the reaction of degeneration was complete, the nerves responding not at all.

(*b*). *The muscles respond by a sluggish contraction to a stimulus, of either kind, applied to the nerve trunk.*

(*c*). *The muscle responds in a similar sluggish manner to induction coil currents applied to the muscle itself.* The reader who wishes to master the intricacies of this part of the subject should consult Professor Erb in Von Ziemssen's volume on *Electro-therapeutics*, pp. 208-225, where he will find a description of several rare variations of electrical reactions.

136. **Sensory nerves.**—There is but little to be said on the subject of alterations in the electrical reactions of sensory nerves. Simple increase of sensibility and simple decrease of sensibility can be detected, and apparently the degree of electrical sensibility corresponds rather with the degree of perception of pain than with that of perception of tactile sensations. This has been determined in diseases in which these two forms of sensibility are often affected in unequal degrees.

For investigating the electro-cutaneous sensibility the interrupted current must be employed, and it is as important to notice and take into consideration the amount of skin resistance, as it was in examining the muscles, and in the absence of a suitable galvanometer, the sledge coil must be used, and the distance of secondary coil from primary must be noted and recorded. For testing the sensibility of the cutaneous nerves one may use a metallic brush for the active electrode and

should not moisten the surface of the skin; or an electrode devised by Erb may be used. It consists (fig. 63) of a bundle of 400 metallic wires sheathed and varnished, enclosed in a vulcanite case of about two centimetres in diameter. At one end the wires are all put in metallic communication, and are attached to an ordinary rheophore handle, the other end is polished, so that when applied to the skin it has the effect of a smooth surface. It covers an area of skin of about two centimetres in diameter, and into this the current enters

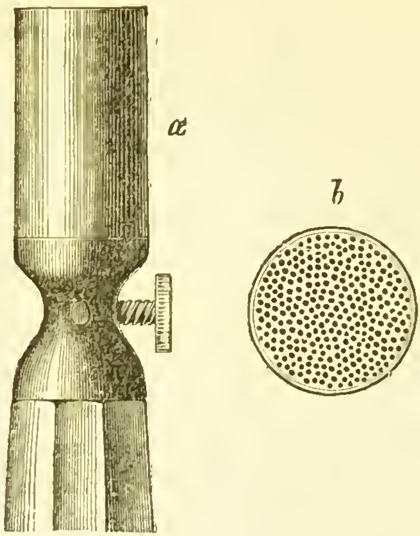

FIG. 63.—Cutaneous testing electrode. *a*. Side view. *b*. End view.

in 400 parts. Thus a more regular action on the numerous nerve terminations is secured, and with the interrupted current the degree of stimulus may be estimated for the first appearance of sensation, and for the first perception of pain. The following remarks* on the

* "Lectures on Injuries of Nerves," *Lancet*, June, 1887, Mr. A. A. Bowlby.

subject of estimating anæsthesia, are of great value in showing how easy it is to be misled in testing a patient for anæsthesia. "The patient should always be placed in such a position that it is impossible for him to see the hand of the surgeon, or the area which is under observation. He should not be allowed to move the finger or other part touched, for thereby the muscular sense comes to the aid, and falsifies observations. The impact of the instrument used should be very light, for a patient can frequently discern friction on an anæsthetic surface by means of vibrations carried by the tissues to surrounding healthy nerves. . . . . I have often seen the sensory power of a presumably anæsthetic part tested by rubbing the part with the finger while the patient's eyes were averted, and almost always with the result that the stimulus was correctly perceived, and that a returning sense of touch was diagnosed by the investigator. Such a conclusion is entirely erroneous, for as Létiévant has pointed out, any person can perceive friction applied even to the finger of another person, if it be held between the bases of two of his own fingers, *i.e.*, the vibrations are conveyed to and appreciated by the nerves of the surrounding digits. How much more must this be so in the case of a divided median nerve when healthy nerves are present on part of the very finger to which the friction is applied. Friction should, therefore, never be used as a test of sensation, for the same reason the part which is being examined should never be pushed or thrust away from the position in which it lies."

An ingenious method of testing the sensibility of a patient is to use one's own finger-tips as the electrode, for by proceeding in this way the operator has his own sensations as a guide, and can use them to check the

patient's statements. A systematic examination of the different parts of the body by this method will show how greatly the sensibility varies in different regions. To do this one electrode is applied to the patient, and one to the operator, the circuit will then be closed when the operator places his finger on the patient. The operator then feels the current which is passing to the patient, and can judge from his own sensations of the degree of sensibility possessed by the patient.

137. **Nerves of special senses.**—*The auditory nerve.*—Of the nerves of special sense there is one which we may discuss at present, namely, the auditory, because of the importance which the electrical treatment of *tinnitus aurium* has given to it. We have already pointed out that in health it is possible to obtain reactions when a battery current passes through the auditory nerve, and that like the motor nerves, the auditory responds more readily to KC than to AC, and generally exhibits the same electrical reactions, the response being the production of a subjective sensation of sound ; but in certain cases of *tinnitus* the auditory nerve answers to electrical currents much more readily than it does in health, being affected even by a current of the strength of one milliampère. In these cases it is supposed that there is a state of hyperæsthesia or of irritation in the nerve, and that the tinnitus is really the expression of that irritable state. In the simplest form of hyperæsthesia the kathodal closure gives loud sounds which readily persist so long as the current is flowing (KD), but cease at once with the opening of the circuit, while the anode (anodal closure) diminishes or abolishes the sound, which does not return during the passage of the current, and often not for hours after the current has been stopped, provided that the stoppage be very

gradual, so as to diminish as far as possible the effect of anodal opening.

In the examination of the reactions of the auditory nerve there are many difficulties, first in the application of the current without producing fresh noises from accidental movements of the electrode, second, from the tendency of the other ear to respond and so confuse the results.

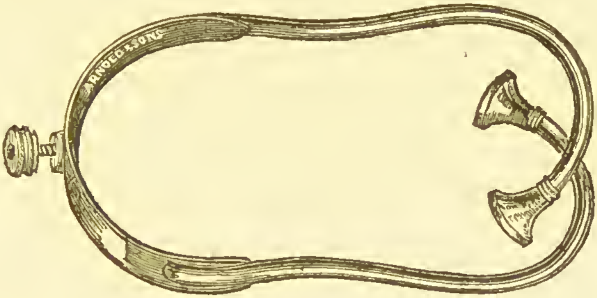

FIG. 64.—Aural electrod

To apply the current to the auditory nerve it has been recommended that the patient should sit down with his head resting on a table, in such a way that the ear to be treated is uppermost; the external auditory meatus can then be filled with water, and the electrode introduced into it just so far as to dip into the water; the other electrode may be applied to the sternum, to the nape of the neck, or may be held in the hand, or it may be arranged underneath the other ear, the side of the patient's head resting upon it, the current is then gently and gradually turned on.

Of these several positions of the indifferent electrode the last is probably the worst, for it is difficult to see how the effect of the anode can be brought to bear upon one ear without at the same time producing a kathodal zone near the other ear; but wherever the negative

electrode may be placed, there is always some likelihood, if both ears are very sensitive, that the ear not operated on may also give response, coming as it does within a region of virtual kathode, when the anode is applied to the other ear, and *vice versâ*, and indeed, if one ear be much more sensitive than the other, the application of a current to the less sensitive one may produce sounds in the opposite ear only, and then the normal formula of the auditory nerve may appear to be reversed, the responses being produced by a virtual kathode in the more sensitive ear when the actual anode is applied to the other, and so on, a state of things very likely to confuse the experimenter, particularly when his patient is not very intelligent. This reaction of the opposite ear has been called the "paradoxical reaction."

When the external auditory meatus has been filled with water, the sensation is so uncomfortable, and the external sounds are rendered so strange and booming, that it is a matter of difficulty to be sure whether any noises which may be heard are produced by the current or not, and the person experimented on is not at all in a condition for making accurate observations; fortunately the auditory nerve can be stimulated in other and simpler ways, and best of all by a bifurcated or divided electrode, which can be applied to both ears at once. At a pinch a binaural stethoscope answers very well, small pads of moistened sponge being substituted for the ivory ear pieces; these ends may be introduced into the meatus, or may be applied just in front of the tragus and kept in place without unnecessary force by an elastic band or spring.* If a stethoscope is used,

* Messrs. Arnold and Son have made a very convenient divided electrode for this purpose by converting the framework of a light binaural stethoscope.

the lower portion can be removed, and the tubes closed up by small corks, the wire from the battery is clamped to the metal, and the other electrode may be applied to the sternum or back.

Hyperæsthesia of the auditory nerve is frequently met with in all sorts of ear disease, but it is not present in all cases of tinnitus, or subjective noises ; when tinnitus and electric hyperæsthesia coexist the subjective noises are readily influenced and controlled by galvanism, and many brilliant cases of cure have been effected. If the tinnitus does not respond to the electrical test it is much less likely to be benefited by treatment. The opposite condition to electrical hyperæsthesia, namely, electrical torpor of the auditory nerve, is also known.

CHAPTER VIII.

General Therapeutics.

Effects of electricity. Choice of current. Strength of current. Choice of pole. Methods. "General faradisation." Galvano-faradisation. Galvanisation of the cervical sympathetic. Central galvanisation. Self treatment by patients.

138. **Effects of electrical treatment.**—The electrostatic methods of treatment have been already considered in Chapter V. We have now to consider the methods of procedure with the battery and induction coil currents. In either case the treatment may be general or local. Of general methods the one most fully deserving the name is treatment by the electric bath, which will be fully dealt with in the next chapter.

In commencing the study of electro-therapeutics the first questions to arise are the following:—(1) What results are to be expected from the treatment? (2) When should the constant current be used, and when the interrupted? (3) What is the proper strength of current and the proper duration of treatment? (4) What is to be the direction of the current and which pole is to be applied to the affected part? (5) What are the manipulations required?

The effects produced by electrical treatment may be arranged thus:—

(*a*) *Stimulating and trophic effects.*—Electricity acts as a stimulus, not only to the contractile tissues, both directly and through their motor nerves, but also upon the sensory nerves, and through them upon the central nervous system, and upon the vaso-motor system.

All living tissues are stimulated to greater activity by electrical currents, particularly when the currents are variable. D'Arsonval has shown that under the action of a varying current the elimination of urea and carbon dioxide is remarkably increased, even if there be no muscular contraction set up, so that the effect is not merely secondary to the muscular contractions produced by the treatment, he also found some increase with electrostatic charging, but little or none with constant currents.

The improvement in health shown by rickety children, and by anæmic and debilitated persons when they are treated by general electrification with alternating currents is most conspicuous; they increase in weight, they become rosy cheeked, and stronger in every way.

These effects are to a certain extent shared by other modes of stimulation, as for instance, by massage, by treatment with hot and cold douches, followed by friction with rough towels, and so forth; but electricity has certain advantages over these other modes of stimulation, especially in paralytic affections, from its greater power of setting up muscular contractions, and from the ease with which it can be directed to any required parts.

The effects which peripheral stimulation exerts upon the central organs play an important part in electrical treatment, and afford an explanation of the benefits which follow even in cases where the treatment has been applied to the peripheral parts only.

(*b*) *Electrotonic effects.*—These have been already considered in § 109, and the physiological effects there described have been made the basis of a method of treatment by the continuous current. With the alternating currents of the induction coil electrotonic states cannot be expected, but with constant currents the

phenomena of electrotonus should be kept steadily in mind in treatment, for they show when the exciting action of the exalted irritability of kathelectrotonus is to be brought to bear upon a patient, as in paralysis; and when the calming effects of the diminished irritability of anelectrotonus are more desirable, as for the relief of painful and spasmodic affections.

(*c*) *Electrolytic effects.*—The changes produced by electrolysis are most manifest at the surfaces in contact with the electrodes. In general medical treatment these electrolytic effects are undesirable, as they tend to produce injurious local action upon the skin, and are therefore to be guarded against by interposing some moist material between the metal of the electrodes and the surface of the body. In surgery the destruction of tissue by means of electrolysis is used for the cure of nævi and other superficial growths, for the removal of superfluous hairs, and for strictures, and it will be dealt with in a separate chapter. In addition to the electrolytic action at the region of the poles, there is also an interpolar action, through which molecular interchanges take place in the tissues along the whole line between the poles, the exact effects of these interpolar changes cannot be clearly defined, but it may justly be considered as producing some "*alterative*" action; and perhaps some of the trophic effects which follow electrical treatment are due to them.

The different effects may be tabulated as follows:—

A. Stimulating and Trophic.		1. Induction coil. 2. Battery current with interruptions and reversals.
B. Electrotonic.	Stimulating.	Negative pole of battery.
	Anodyne.	Positive pole of battery withou interruptions.

C. Electrolytic.	Caustic action (polar).	Battery current.
	Alterative action (interpolar).	Battery current.
D. Osmotic.	For introducing drugs through the skin.	Battery current, positive pole.

139. **Choice of method.**—Some indications for the choice of current will have been learnt from the last section; generally speaking it may be said that for stimulation pure and simple the induction coil is the best; certainly it is to be preferred in paralysis of muscles if they are able to react to it, but if they present the reaction of degeneration then the constant current may have some advantages. Fashion has had much to do with determining the choice between the two modes of treatment.

Duchenne was a firm believer in the superiority of the the coil treatment for all kinds of paralytic conditions, and Remak was as warm a supporter of the constant current. The former writer declared that he had met with far better results from the interrupted than from the constant current. The latter was as confident of the superiority of his method.

Whatever benefits may be produced by electrolytic or electrotonic effects must be possessed by the battery alone; stimulation, direct and reflex, and trophic effects can be produced by the induction coil, and as these effects form so large a part of what is desired in cases coming for electrical treatment, the induction coil is the instrument for use in the majority of cases.

The battery has been preferred to the coil for the treatment of muscles which show the reaction of degeneration. The reason given for this is that the battery current will make such muscles contract when

the induction coil can no longer do so. If the visible contraction of the muscle were the measure of the good done to it by the treatment, the reason would be a valid one. I have treated large numbers of cases showing RD with the interrupted current, and have obtained very good results in that way, and I consider that it is at least as useful as the battery current for all kinds of paralysis. When the battery current is used, and the electrode is moved over the surface of any part, the effect is that of a very gradually varying strength of current applied in succession to the different parts touched by the electrode, and it differs from the induction coil current chiefly in the rate of variation.

In order to determine whether the battery current is better than the induction coil for treating cases of paralysis, a long series of comparable cases must be treated by each method, and the results examined. I have been able to do this in the electrical department at St. Bartholomew's Hospital to a considerable extent, and I am satisfied that good results can be obtained with both methods. As it is probable that the effects of the two methods do not exactly coincide, it seems reasonable to advise treatment by both; for example, to give a patient with muscles showing RD a treatment with the battery and with the induction coil, at each visit.

140. **Strength of current.**—In determining the strength of current it is necessary to remember that but little good is likely to follow torture, and that no needless pain should be inflicted upon the patient. With the coil the operator must gauge the strength of his current upon himself first, and must repeat the test with every increase in its strength; a strict adherence to this rule is the best plan by far of ensuring the proper

amount of caution. Patients as a rule are extremely intolerant of painful shocks, and it must be remembered that the very name of electricity is enough to make many patients at least a little anxious or alarmed on their first trial of the remedy; the strange look of the apparatus, with its gleaming knobs, the clicking or humming noises which it gives out, and above all the mystery which electricity has for the public, combine to make every patient feel nervous, and the operator, himself quite familiar with his apparatus, is very likely to forget this. It is therefore wise always to exercise carefulness in the management of the instruments, in order not to appear to the patient to be reckless in handling them.

With battery currents the galvanometer provides the means of regulating the dosage. For most forms of local treatment five milliampères is sufficient, and may be too much for children or sensitive or nervous people, at the commencement of a course of treatment; and this current must not be switched on or off abruptly, but only very gradually, the patient being carefully watched for any signs of pain or discomfort. The current collector (§ 79) must be properly made and tested from time to time to see that it allows of alterations in the number of cells without any breaks of circuit; when the applications are made to any part of the head or neck, additional care must be exercised, the effect upon the brain being very peculiar and unpleasant, especially at make and break. When large currents are required in the electrolysis of nævi or tumours, an anæsthetic must be used. In Apostoli's treatment no anæsthetic is used, although the current may exceed 100 milliampères. Toleration of so large a current is rendered possible by the use of a very large electrode for the cutaneous sur-

face to reduce the density of the current per unit of area, and by the insensitiveness of the uterus to which the other pole is applied.

The duration of each sitting may be on an average en minutes, but here again the patient's feelings must be taken into account, and the time shortened or lengthened as may seem advisable in each particular case.

The number of sittings varies very much, usually a considerable number are required. It is best to tell the patient at the commencement that he must not expect magical and sudden cure, but rather a gradual slow improvement. In some cases of infantile paralysis it may be necessary to continue treatment for 12 months. As a general rule it may be said that at least a month of treatment, with two or three sittings a week, is required to produce permanent benefit, but of course there are exceptions, and it is not possible to lay down any precise rules. It is usual for improvement to begin early if the treatment is likely to do good. In that case the patient will be encouraged to persevere. If at the end of a month of regular treatment there is no visible change, or if the improvement has ceased to be progressive, then the treatment may be discontinued.

141. **The choice of pole.**—With the alternate currents of the secondary coil the influence of pole is reduced to a minimum, and the two electrodes may be considered to be of equal, or nearly equal value; with continuous currents there are well marked differences in the effects produced at the two poles. From electrolysis the region of the anode or positive pole becomes acid, and that of the negative alkaline in reaction, and there is a tendency to produce injury to the skin from the chemical products of the electrolysis, if

the currents be large, or if the electrodes are left long in one position.

The sedative effect of the anode (§ 109) determines its use in neuralgia, sciatica, spasm and tinnitus aurium, while the stimulating effect of the kathode and the greater ease with which it causes muscular contraction have determined the use of the negative pole in the treatment of paralysis. It is not possible to generalise further about the choice of pole, but instructions will be found in the chapters on treatment.

A simple rule has been laid down for the direction of the flow of current in medical practice by Remak, who advises that the current should pass along the nerve fibres in the direction in which they conduct, namely, downwards to the periphery for treatment of motor affections, and upwards from the periphery for sensory affections.

Brenner prefers to consider that the direction of the current is of less importance than the influence of the poles; and we should therefore speak of the choice of pole rather than the choice of the direction of the current, because the current does not run in straight lines from anode to kathode; however, the distinction between direction of flow and choice of pole is after all a subtle one. To apply the kathode to the paralysed thumb muscles, the anode being at the nape of the neck, may reasonably be spoken of either as treatment by a descending current or as treatment by the negative pole. Those who object to speak of the influence of direction of current base their objections on the fact represented in fig. 60, that round a pole applied to any part of the surface of the body the flow of current is not in one but in every direction, and therefore there can be no definite direction of the flow in the muscle under treatment, the

effects being effects of pole and not effects of direction of current. However, with the indifferent electrode central, and the active one peripheral, it is permissible to speak of treatment with descending currents when the active electrode is the kathode, and of ascending currents when it is the anode; the words ascending and descending having reference to the general direction from anode to kathode, and not implying any theory of the physiological or therapeutical importance of the direction of the flow at the seat of disease. (See § 110).

142. **Methods.**—Most electrical treatment is now carried out by using a single active electrode, and an indifferent electrode. The active electrode may be three, four, or five centimetres in diameter according to the extent of surface to be included in the treatment; the electrodes must be well moistened with warm water, the indifferent one in its sheath is then pushed down the back of the neck for patients who are dressed and sitting up, or it is placed under the hips for patients lying down. The part to be treated is then bathed with warm water, and the active electrode applied, and the current slowly raised to a proper strength; with the battery current three, five, or ten milliampères or more if necessary. With a coil and Giltay's galvanometer a current of less than one milliampère will be strongly felt. The active electrode is then moved slowly over the whole of the affected part (*labile* method) or it is kept still in one place (*stabile* method). The circuit may be closed and opened for the sake of producing muscular contractions, or may be even reversed by means of a commutator, for the same purpose. These reversals are especially powerful in exciting muscular contraction.

It is sometimes useful to have the indifferent elec-

trode also in the neighbourhood of the part under treatment; by doing this the current can be concentrated through the part tested.

In testing or treating the muscles of the hand for instance, it is often convenient to lay the indifferent electrode under the palm while the dorsum is being treated, and *vice versâ.*

Sometimes too a bowl of water is useful as a medium between the electrode and the patient, who may dip a hand into the water in which one electrode is placed, and have the other electrode at the nape of the neck, or he may have two such bowls of water and put one extremity in each, when the current is to traverse two limbs at once.

When sensory impressions are chiefly desired, the skin is treated dry with a metallic brush of very fine wires; a long secondary coil of many turns is most suitable for use with this.

The induction current is to be employed where tonic or stimulating effects are chiefly desired, and with this object it is valuable in the treatment of paralysis and anæsthesia. Where the involuntary muscle requires to be roused, the battery current with interruptions and reversals is probably more effectual; thus the abdomen and the rectum may be treated for constipation, and the bladder or the uterus for atonic conditions.

Reference to the chapter on diagnosis explains the methods of exciting the individual muscles and nerve trunks, and the treatment consists simply in moving the wet surface of the electrode slowly over the moistened skin covering the muscles with a sliding and a rolling movement. This sliding movement is a guide to the proper degree of moisture necessary. If either the skin or the surface of the electrode be too dry the latter

will not slip smoothly, but will seem to stick, or move harshly. When this is felt the electrode must be moistened afresh.

It must not be assumed that the degree of benefit from treatment can be measured by the amount of visible contraction of the muscles, for in addition to the exercise so produced there are vaso-motor effects, and reflex effects through the centres in the cord, both of which take part in bringing about the final results.

The duration of each application should be about ten minutes, and this time must be distributed over the muscles or other parts needing treatment. When the dry brush and painful currents are employed, five minutes will usually be quite long enough, and the patient must on no account be reduced to a state of exhaustion from over-treatment. The operator should always try the current by experiment on his own muscles, in order to know exactly what amount of discomfort or pain his patient is called upon to bear.

143. **"General faradisation."**—We can now consider the methods of general treatment. The old plan of treating patients by means of metallic electrodes placed in the two hands may be regarded as a rude attempt at general electrification. Drs. Beard and Rockwell have elaborated a method of "general faradisation," the advantages of which they claim to have been the first to bring before the notice of the medical profession.

The object aimed at is "to bring every portion of the body in turn under the influence of the treatment so far as is possible by external applications."

They consider that this is best accomplished by placing one pole of the induction coil under the feet or gluteal region while the other is moved over the general body surface. The patient should stand or sit upon the

surface of a large metal electrode covered with moist flannel, this must be kept warm by means of a hot water bottle or some other contrivance, as the treatment lasts for from ten to twenty minutes. The other, active, electrode is then to be moved over the various parts of the body, two or three minutes being given to the head, neck, back, abdomen, arms, and legs, in order.

The application to the limbs is less important, and may be omitted in certain cases.

The active electrode should consist of a metal disc or ball covered over by a large sponge of six inches in diameter, and kept moist with hot water. The object of using electrodes of large size is that by their means the current is rendered less painful, and consequently the patient can bear stronger applications; the use of the operator's hand as the active electrode* is also recommended by Dr. Beard as its tactile sensibility makes it easy for the operator to gauge both the amount of pressure he is employing, and also the force of the current used. When the hand is to be used as the active electrode the operator should put himself in the circuit by holding the wet sponge in his other hand, the current then passes through his own body from hand to hand and so to the patient. He can vary the force of the current by altering the degree of pressure with which he holds the sponge, for when it is firmly grasped the current passes more readily and is increased, and when the grasp is relaxed the current is diminished; no bad results follow to the operator, on the contrary he shares with his patient the benefits of the treatment, and considerable development of the muscles of the arms is said to follow.

* This mode of application is spoken of as the "electric hand," or the "hand electrode." It was employed by Duchenne.

The patient may be seated while the upper part of the body is under treatment, but should stand up if possible for the application to the hips and thighs. A loose garment like a shirt or night-gown can be worn, or a large shawl or blanket may be thrown round the patient. The electrode can then easily be manipulated and moved over the surface of the body without exposure.

In the region of the head the forehead and the vertex are the most important; if the hair is at all long or thick it may be moistened, to diminish its resistance. The treatment of the back of the neck and the whole region of the spine is considered to be extremely important and should be thoroughly carried out, the electrode being slowly moved up and down along the whole length of the back.

The sensations felt by the patient should be of an agreeable nature, a pleasant thrill, without any sort of pain or discomfort. The operator must bear in mind that the sensibility of the surface varies in different parts of the body and he must adapt the force of the current to suit such variations, using the hand by preference for treating those parts which are most sensitive.

The results of the treatment are mainly tonic in their nature, a feeling of vigour follows, depression or fatigue are relieved, the appetite is increased, the patient sleeps more soundly, there is an increase in the firmness of the muscles, and an improvement in the circulation. In some patients these results follow promptly, in others their development is more gradual; the same variability in the response of patients to other forms of electrical treatment has been observed by others.

The treatment should be carried out two or three times a week, or every other day. Currents sufficiently strong to cause muscular contraction should be em-

ployed, as soon as the patient has become accustomed to the treatment and is able to bear them without apprehension.*

The process just described is doubtless useful, but there is a decided risk of the patient being chilled. The electric bath produces the same results with more comfort to the patient.

144. **Galvano-faradisation.**—Dr. De Watteville has recommended the simultaneous use of the continuous and the interrupted currents under the above name. The method consists in "uniting the secondary induction coil and the galvanic battery in one circuit by connecting with a wire the negative pole of the one with the positive of the other, attaching the electrodes to the two extreme poles and sending both currents together through the body," we are told that "the effects of the faradic current are greatly enhanced by a simultaneous galvanization, because the points upon which the stimulus falls are in a state of exalted excitability or kathelectrotonus. Owing to the "refreshing" properties of the galvanic current upon muscle, the fatigue and exhaustion which might otherwise be the consequence of energetic faradisation are avoided." Dr. De Watteville has a very high opinion of the advantage of this mode of treatment, particularly for electrisation of the abdominal viscera, and in rheumatic conditions, and in atrophic paralysis.

The strength of each component may be about the same as when either is being used alone.

145. **Central galvanisation.**—This is a plan of applying electrical currents to the nerve centres, also

* For a full account of general faradisation, with figures, the reader should consult *Medical and Surgical Uses of Electricity.*—Beard and Rockwell. H. K. Lewis.

introduced by Drs. Beard and Rockwell. It consists "in placing the negative pole at the epigastrium, while the positive pole is applied to certain parts of the head (chiefly the vertex), to the sympathetic and pneumogastric in the neck, and down the whole length of the spine from the first to the last vertebra." It is said to be useful in cases of hysteria, neurasthenia, sleeplessness, dyspepsia, and other complaints. The duration of the treatment may be about ten minutes, the position of the negative pole must be changed from time to time, to prevent any bad electrolytic effects upon the surface of the skin beneath it. The strength of current should be varied between five and ten milliampères, according to the part under treatment.

For the application of continuous currents to the skull three methods have been proposed, the longitudinal, the tranverse and the oblique. In the first the electrodes are applied to the forehead and occiput, in the second they are placed either on the two sides of the frontal bone, or on the mastoid processes, in the last they are applied to the forehead on one side and the nape of the neck. The third method is considered specially useful, because the current then follows the direction of the motor fibres from the cortex to the anterior pyramids of the medulla. The anode is usually placed in front. In all three methods it is recommended to use large electrodes and weak currents very gradually increased, and the duration of a sitting should not exceed five minutes.

146. **Galvanisation of the cervical sympathetic.** —A good deal has been written of this proceeding, but as Dr. De Watteville has pointed out in an entertaining and caustic article in *Brain*,* it is extremely doubtful

* "An Electro-therapeutical Superstition." *Brain*, iv., 1881, p. 207. A. De Watteville.

whether the cervical sympathetic has ever been appreciably influenced by electrical treatment. At least none of the ordinary physiological effects on the pupil or the blood vessels of the head and neck of stimulation of the sympathetic are produced. The treatment is carried out by placing one electrode below the ear and the other at the nape of the neck, and passing a weak current. All sorts of advantages have been claimed for this method, which has become an established part of the routine treatment of many morbid states of the central nervous system, so that in Erb's opinion it should be carried out "in every case where it is hoped to act on the circulation and nutrition of certain parts of the brain." Dr. Moritz Meyer's plan is to place a medium sized electrode at the angle of the jaw, with its surface directed backwards and upwards towards the vertebral column. The other pole should be larger, and applied to the opposite side of the back of the neck, on a level with the fifth, sixth, or seventh cervical vertebra. The kathode is usually placed in front, but not always; the current should be two to five milliampères, and the duration one to three minutes, the application *stabile*. In certain cases both sides may be treated successively. As this treatment must involve all the other important nervous parts of the neck and the base of the skull, as well as the cervical sympathetic, it would be better to adopt Dr. De Watteville's suggestion, and speak of *sub-aural galvanisation*, rather than of galvanisation of the sympathetic.

147. **Self-treatment by patients.**—It is a matter of the greatest importance that all electrical treatment should be carried out by the medical man himself whenever this is possible, and if it is not possible for him to do so then at least he should supervise the treatment

as often as he can. When patients are left to themselves with a battery, the results are uniformly unsatisfactory, and the usual consequence is solely to bring electrical treatment into undeserved discredit. It would be very nearly as reasonable for a patient to attempt to act as his own dentist as for him to try to cure himself by means of a battery without full medical advice and constant supervision. Only those who use batteries regularly are able to deal with the difficulties of making them work properly, and it is therefore absurd to place one in the hands of a patient who cannot even know whether it be working properly or not.

An exception may be made in favour of treatment by the induction coil when a long course is necessary for a particular case. The manipulations may then be carried out by a trained nurse provided she be given at the commencement of the case a few careful lessons in the anatomy of the part to be treated, and in the manipulations to be performed; she must be supervised at frequent intervals by the medical man in charge of the patient, who should never omit to make measurements and tests from time to time, to ascertain what progress is being made, and to prevent the case from being left in the sole charge of the nurse.

So too with the treatment of infantile paralysis by means of a coil and bath-tub applied daily at bedtime; it is impossible for the doctor to see to it during the whole period of treatment, and one person, the nurse or mother, must be carefully shown what to do for the particular case. The periodical testing by a capable medical man must not be omitted. It is much to be desired that in future the application of electricity as a therapeutic agent may be restricted as much as possible to the hands of the qualified medical prac-

titioner, and it rests with medical men themselves to hasten this end.

With increased knowledge of electrical matters medical men will quickly find the advantage of carrying out electrical treatment for themselves. To hand over a valuable means of relieving their patients to outsiders is obviously unwise, and not infrequently it leads to results which only tend to throw discredit upon a method of treatment which deserves to be far more widely valued than it is at present.

Treatment which requires the use of the continuous current demands much greater technical and medical training than the use of the induction coil for simple stimulation of nerve and muscle.

It may be taken as a good working rule that none but medical men should be allowed to carry out treatment by the battery current. It should not be entrusted to any other person. I have often known patients improve quickly under proper and methodical applications, who had previously gone through courses of perfunctory electrical treatment at the hands of unskilled persons without the slightest benefit.

CHAPTER IX.

The Electric Bath.

The bath. Accessory apparatus. The resistance of the bath. The mode of application. The use of the electric light mains. Hot air or vapour electric bath. Uses in chronic rheumatoid arthritis. Gout. Sciatica and lumbago. Nervous affections. Rickets. Anæmia. Raynaud's disease.

148. **The bath.**—The electric bath is used in the treatment of morbid conditions which affect the whole system, because it provides a convenient and agreeable way of applying general electrification, a mode of treatment of great value whenever general stimulating, and tonic effects are required.

The publication of Duchenne's *Électrisation localisée*, which gave so great an impetus to systematic electrical treatment, tended also to produce the impression that electricity was useful only in nervous diseases, and that local applications to the affected nerves and muscles formed the only plan of electrical treatment worth following.

General electrification, however, has a very powerful trophic influence upon the body, and is most useful in the treatment of many morbid states, such as debility, anæmia and chlorosis, rickets, rheumatism, rheumatoid arthritis, gout, sciatica and lumbago, and generally in diseases due to impaired and defective nutrition ; also in general neuritis after diphtheria, influenza and other specific fevers.

General electrification carried out by means of an electric bath is agreeable to the patient, and far more effica-

cious than the process of "general faradisation" or of "central galvanisation" referred to in the last chapter.

It is unfortunate that the electric bath has been taken up of late by unscrupulous persons, and so has been in danger of falling into discredit with medical men.

The bath itself should be made of porcelain or earthenware, or it may be made of wood. The former is the best, as it is easily kept clean and nice looking.

A bath five feet six inches in length is better than one which is six feet long.

The water in the bath should be agreeably warm, averaging 99° F., but it may be slightly warmer or cooler to suit the wishes of the patient. It is noteworthy that a difference of one or two degrees makes a great difference in the sensations of warmth felt by the patient at these temperatures. The bath should be so filled with water that when the patient lies in it the whole body and the shoulders may be covered. A bath thermometer must always be used to ascertain and regulate the temperature.

149. **The apparatus required.**—Two electrodes in the form of metal plates placed at the head and foot of the bath are required, and they should always be kept clean and bright. These metal plates are provided with binding screws to which the battery wires are attached (fig. 65). The best metal is copper. Zinc plates may also be used. It is no use having these metal sheets plated, as is sometimes done for appearance sake, for the plating quickly leaves the positive pole. The electrode placed at the head of the bath is usually the larger, and may measure eighteen inches by twelve, that at the lower end of the bath being eleven inches by nine. Smaller plates are sometimes used for the hips and knees when it is wished to localise the current more

or less at those parts. A moveable paddle connected to the pole at the foot of the bath may be used for this purpose. It may be used either to supplement the foot

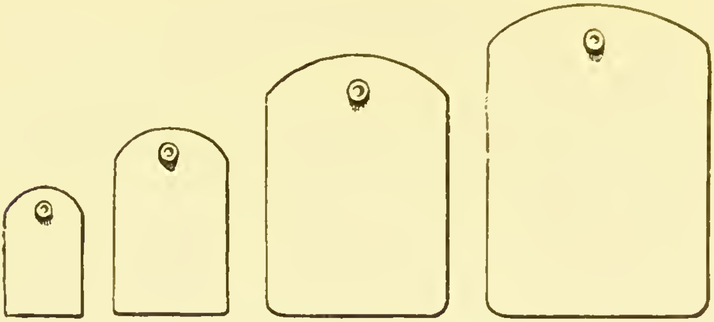

FIG. 65.—Electrodes for the bath.

plate or to replace it. The water should always be deep enough in the bath to cover the plates.

The shoulders and back of the patient are kept from

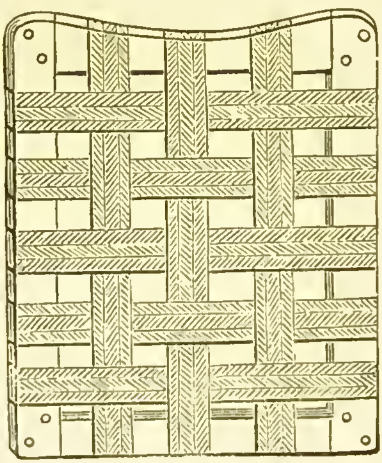

FIG. 66.—Back rest.

touching the plate at the head of the bath by a rest made of wood, something like a picture frame having pieces of webbing stretching across (fig. 66). The light

wicker fire screens which are made to fit on to the backs of chairs are also very convenient and comfortable for the purpose.

The feet may be allowed to touch the electrode at their end of the bath because the epidermis on the soles is thick enough to take care of itself. If a patient prefers it, the feet need not be placed in actual contact with the metal, but they should be kept in close proximity to it. A part only of the total current in circuit traverses the body, the remainder passing through the water in which it is immersed. The water in the bath offers a broad conducting medium with a large transverse sectional area, several times larger than the patient and therefore a considerable part of the current traverses the water and is altogether lost to the patient.

150. **The resistance of the bath.**—The resistance in an electric bath will vary with its length, with the depth to which it is filled, and with the temperature of the water.

Dr. Hedley* has contributed largely to our knowledge of the physics of the electric bath, and his book should be studied by all those who are interested in the subject. He has given the following figures as determined for a particular bath, six feet long, made of oak :—

				Resistance.
Height of water,	15 inches	with body	...	162 ohms.
,, ,,	12 ,,	,,	...	205 ,,
,, ,,	10 ,,	without body	...	245 ,,
,, ,,	7 ,,	,,	...	357 ,,
,, ,,	5 ,,	,,	...	510 ,,

* *Hydro-Electric Methods in Medicine.* London, H. K. Lewis, 1892.

Resistance of bath with water at different temperatures :—

Temperature.			Resistance.
98 Fahr.	...	...	165 ohms.
92 ,,	...	...	194 ,,
87 ,,	...	...	264 ,,

For the porcelain bath used by myself, five feet six inches long, I have found the following resistances :—

Temperature.		Depth of Water.		Resistance.
100	...	14 inches	...	152 ohms.
100	...	12 ,,	...	190 ,,

Another question of interest with the electric bath is the following :—How much of the total current passes through the patient, and how much is conveyed by the water ? The answer will depend upon the temperature of the water, and upon the volume of water in the bath; the problem is best attacked by regarding the condition as one of a divided or branched circuit ; the water being one and the patient the other of two conductors ; the proportion of current traversing each will depend upon their relative resistances. Dr. Steavenson* gave one-fifth as the fraction of current passing through the patient. In the first edition of this book one-eighth was suggested as more probable ; the calculation being made from the observation of a galvanometer, first before the patient entered the bath, and secondly, when the patient was immersed. The increase in the current when the patient was in the bath, the electromotive force remaining constant, was taken as the measure of the amount carried by the body.

M. Meylan† has recently contributed some further

* *Lancet*, 1891, vol. i.

† *Revue internationale d'électricité.* Nov., 1894.

data upon this question. He measured the resistance of a bath first with a patient immersed ; secondly with the patient removed, the water as before ; and thirdly with the patient removed, but with water added to bring the level up to that which it had when the patient was in it.

The measurements were as follows :—

A. Water and patient ...	... 136	ohms resistance.
B. Water only	... 156	,, ,,
C. Water, with water added	... 138	,, ,,

By calculating out these figures we arrive at 1060 ohms as the patient's resistance, and 736 ohms as that of the equivalent bulk of water added in experiment C. The resistance of the patient compared to that of his own volume of water spread out in a layer over the area of the bath was roughly as 4 is to 3. The cubic measurement of an average sized man is three cubic feet or about eighteen and a half gallons.

If we compare the resistance of the water only, 156 ohms, with that of the patient, 1060 ohms, we find that under the conditions of the particular bath, the patient's body was carrying about one-eighth of the current.

As the current which traverses the water does not affect the patient and therefore may be considered as wasted, it follows that for economy of current the amount of water used in the bath should be no more than enough to cover the patient comfortably. On the other hand a large volume of water retains its heat better for the time required for the bath.

If salt or acid is added to the bath, the water becomes a better conductor than before, and the patient's share of the total current passing will be reduced. It is therefore useless and objectionable to make such additions to the water. In spite of this fact, some

writers have advised it to be done. The duration of the bath should be from ten to fifteen minutes. The first five or six baths may be given on consecutive days, and then every other day until the end of the course. A course may consist of thirteen or fourteen baths. A patient may have more if he wishes, and if he is continuing to progress; but often after a course is over the patient's condition will continue to show improvement after the baths have been left off.

151. **The mode of administration.**—The battery current for a bath must be very gradually raised until the galvanometer registers 150 to 200 milliampères, of which the patient really carries a current of from 18 to 24 milliampères; but it is best for the first few baths to use a current not exceeding 100 milliampères. A battery of large Leclanché cells answers very well, thirty or forty of these may be connected with a switch board having a double or single collector (§ 79) and a commutator (§ 80); a galvanometer graduated to read up to 250 milliampères must be included in the circuit. An induction apparatus is also required, it should have a secondary coil wound with few turns (§ 68), and need not be a large one, but its vibrator should work very smoothly, and the means of graduating its strength must admit of careful adjustment.

The patient after entering the bath should be allowed a few minutes to recover from the reaction produced by the warm water before the current is turned on. The current should be increased slowly and cautiously, and the galvanometer watched, and at the termination of the bath the current must be reduced as slowly. The direction of flow should generally be from the head to the feet, the anode being at the upper end of the bath, and the kathode at its foot. There is

no certain knowledge of the effect of the direction of flow in treatment by the constant current bath, but the direction here given represents the views of the late Dr. Steavenson, in the treatment of rheumatoid arthritis. A medical man should always be present to regulate, increase, or diminish the strength of the current. The patient can wear an ordinary bathing costume. With female patients the presence of a nurse or a maid is necessary, but the medical man should also remain in the bath-room while the current is flowing. An arrangement is needed (§§ 79, 81) for gradually increasing the strength of the current without any interruptions taking place, so that all chance of giving a patient a shock is avoided. With the large currents used this is most important. As the current is slowly augmented the first sensation experienced by the patient is usually a slight pricking or tingling at the ankles or at the knees. A galvanic taste may be perceived as the current becomes stronger. Should the patient's head feel full or throbbing during the administration of the bath a cold wet towel may be placed on the top of the head. And if any faintness is caused, the current must be reduced. An electric bath must not be taken too soon after a full meal. During the bath the pulse rate is said to be diminished, as are also the respirations. After the bath the skin of the back near to the upper electrode will be found of a bright red hue, this will gradually pass off in an hour or two. After dressing, the patient should rest for ten or fifteen minutes before going out into the open air, and should not immediately engage in exhausting exercise. After an electric bath there appears to be no particular tendency to catch cold and the patient generally feels exhilarated and better. Should there be any sign of

languor or depression after a bath, currents of smaller magnitude should be employed.

The constant current bath is useful in chronic rheumatism, in gout, and in rheumatoid arthritis, also in lumbago and sciatica, though good results may also be obtained in these diseases from the use of the interrupted current, which is the more generally useful of the two, particularly when the effects of general stimulation are required, as in the various states of defective nutrition mentioned above in § 148. If, as may sometimes occur, there be increase of pain from the interrupted current, then the continuous current is to be preferred.

It is an interesting point, and worthy of notice, that when patients with acne of the skin of the back come under the electric bath treatment, the acne quickly disappears.

The currents from the electric light mains may be used with the bath (see § 74); when the supply is alternating the pressure should be reduced by a transformer to six or eight volts, which is a suitable electromotive force to employ, a small adjustable resistance of 100 ohms in circuit is also necessary to adapt the current more closely to the requirements of the case.

The alternating current of the mains produces a smoother sensation than the induction coil, the rise and fall of the individual impulses being less abrupt than with the latter, though it has very similar properties. The induction coil current throws the abdominal muscles into action more readily than the electric lighting current, and generally produces more muscular contraction for a given strength of current.

In applying the continuous electric lighting current of the mains to the bath, care must be taken that the adjustable resistances employed can carry 200 milliampères without over-heating.

A five-candle 100 volt lamp, taking four Watts per candle should just cut down the current to 200 milliampères, the additional resistance of the bath itself further reducing the current on a 100 volt circuit to about 180 milliampères, a current within the limits for practical application in the bath. In such a case the shock at opening and closing could be got over by switching on before the patient enters the bath, switching off after he has left it, and teaching the patient to get in and out of the water at one end of the bath, and to extend himself in it by degrees.

A practical point of great importance in such proceedings is the great leakage to earth from the conductors of the continuous current supply systems. The complete insulation of a bath fitted with water supply pipes and waste pipe connected to earth is impossible, and the patient would in no wise be protected from discharges of serious magnitude by resistances placed upon one only of the two conductors leading to the bath. The leakages would also make the indications of a galvanometer in the bath circuit but an uncertain guide to the current traversing the water.

No one should attempt the feat of giving a safe bath direct off the electric light mains, unless he be, what very few medical men are, an expert in dealing with currents from sources of electromotive force at 100 volts pressure.

It is much better to charge accumulator cells first and to use those (§ 74) for the bath. On the alternating mains a transformer may be used with safety so long as the company's transformers do not break down.

It has been proposed to combine in the electric bath both the battery and the induction coil currents; by connecting the terminals of both instruments to the

electrodes of the bath at one time. It is doubtful whether there are any special advantages in this method (see § 144).

152. **Hot air or vapour electric bath.**—Electricity has been applied to patients when in a hot air or vapour bath. This form of application is said to possess certain therapeutical advantages. Patients who suffer from depression or are unable to bear the water electric bath may be able to take the hot air or vapour electric bath. The bath is given in a cabinet constructed for the purpose. The patient is seated or stands upon a surface connected to one pole. The other pole of the battery can be connected with special electrodes to be applied to different parts of the body. The cabinet contains a hot water coil.

The patient being seated on the stool the hot air or steam is admitted into the cabinet. The vapour is used at a temperature of 90° to 100° F. It produces perspiration and is used for chronic rheumatism, stiffness of the joints, and skin diseases. It is also used at a higher temperature when employed for internal congestions. The vapour bath cannot be borne at such a high temperature, or for so long a time as the hot air, 106° to 110° F. is the usual limit, but the hot air can be borne up to 130°. During the bath the operator applies the electrodes to that part of the patient's body which is to be treated. Sometimes a projecting metal arm is used with the end covered by sponge against which the patient's back or epigastrium can rest. This projecting arm is fixed to the back or side of the cabinet and connected with one of the poles of the battery.

A hot air or vapour electric bath occupies fifteen or twenty minutes. At the conclusion the patient should be cooled down by a shower bath. A drain at the

bottom of the bath carries off the moisture. Although the patient is enveloped with hot air or vapour the electricity can only be conveyed by contact of the electrodes; it is not conducted by spray or steam, as the following experiment shows:—Pure water and salt and water in fine spray were forced out of a metal nozzle connected with one pole of a battery, the jet was directed on to a metal receiver connected with the other pole and a delicate galvanometer included in what would have been the circuit had the vapour conducted any current, but no deflection of the needle was produced. A hot air or vapour electric bath is therefore nothing more than the application of electricity to a patient whose skin is rendered a better conductor through the warmth and perspiration that is induced. The skin is softened and so rendered a better conductor. The vapour bath is considered more relaxing and soothing than the hot air bath. Although the current is not conveyed by vapour or steam, it may be carried by an unbroken jet of water; and douches can be contrived which will at the same time electrify a patient, if he stand or sit upon a conductor so as to complete the circuit.

153. **Chronic rheumatoid arthritis.**—An affection for which the continuous current electric bath is most useful is chronic rheumatoid arthritis. Electric baths will not cure inveterate cases, but in early cases they will do very much to arrest the progress of the disease, to reduce the pain and swelling of the joints, and otherwise to produce amelioration in the symptoms. When the hands are mainly affected a pair of metal handles of suitable sizes (fig. 67) covered with flannel have been employed to concentrate the current upon the parts.

The handles are attached to one pole of the battery, and take the place of the foot plate. The current is thus concentrated upon the arms and hands. But this local application of the current should only be used for about the last five minutes of the bath ; it should never altogether take the place of the general bath, which exerts an influence on the whole system.

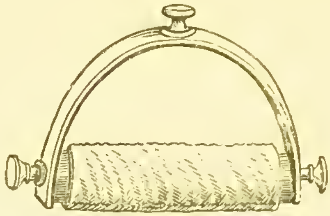

FIG. 67.—Handle for rheumatoid arthritis.

The hands may also be made to grasp a metal bar supported across the bath and covered with moistened flannel (fig. 68). In this position the hands are raised out of the water and carry the whole current, which must be adjusted to suit the altered conditions. When concentrated in this manner on the hands the patient cannot bear more than ten or fifteen milliampères. When changes in the direction of the current are to be made, the current must first be reduced to zero and then increased again. If the current were broken or reversed suddenly, the patient would receive a very unpleasant shock.

After the completion of a course of baths it is generally possible to notice some improvement in the condition of the patient. A patient for instance who could only climb upstairs slowly and painfully becomes able to make the ascent without assistance; or a woman who could not hold her needle or perform her household

work at all well finds that she is able to do so better than before. The direction of the current in the treatment of rheumatic affections should be with the positive pole at the head of the bath.

When the larger joints, such as the knees, hips, or shoulders, are the seat of rheumatoid arthritis, the current can be localised by the use of smaller metal plates placed on either side of the bath so as to include the affected joints between them. The joints should be afterwards subjected to rubbing and passive movements. Local arm baths or foot baths are sometimes given when one limb or joint only is affected. An oval basin or a wooden bath is the best, and two small metal plates attached to the respective poles of a battery are placed one on either side of the affected member and a current allowed to pass. Sometimes one electrode only is placed in the water, the other (a disc electrode attached to the negative pole) being applied to the affected joint or limb; for instance, to a rheumatic knee or to the arm. But ordinary local treatment, without the bath, seems to be more suitable for these localised affections.

FIG. 68.—Bar electrode.

Gonorrhœal rheumatism has also been treated by electric baths on the same plan as that followed in the treatment of rheu-

matoid arthritis, but not with quite such satisfactory results. It is useful to employ passive movements as well for the affected limbs.

154. **Gout.**—The continuous current bath is said to be useful in gout, more especially in old standing and chronic cases. It has been suggested that it acts in part by eliminating the urate of soda through an electrolytic action, but the proof of this is still wanting. It improves the condition of the joints and should be used after the acute attacks have passed off.

155. **Sciatica and lumbago.**—These affections are suited for treatment by the electric bath. Very good results are obtained by ordinary local treatment in both these conditions, but it is often more convenient and more agreeable to the patient to be treated by means of the bath, and the results are quite satisfactory. A course of twelve baths usually suffices to effect a cure. The direction of the current seems to be unimportant, an electrode covered with flannel may be placed under the thigh on the affected side, in addition to the usual foot electrode, the other pole remaining behind the shoulders as usual.

From a very considerable number of cases of rheumatism, rheumatoid arthritis and sciatica treated by the electric bath, I am of opinion that the induction coil is as useful as the constant battery current; indeed, I have sometimes found that the patient remained unimproved by the latter, and then began to progress favourably when the induction coil was substituted for it. In other cases, I have known a patient improve under the constant current; and, returning again a year later with the same symptoms, improve equally well under induction coil treatment. It sometimes happens that the interrupted current increases

the pain in sciatica. When this is the case the constant current acts more favourably.

This makes it difficult to settle the rationale of the action of electricity in these disorders. One might, perhaps, suppose that the improvement under the interrupted current was due to the effect of systematic general stimulation, while the constant current might act by some interpolar electrolytic effect.

For the last two years I have used the alternating current of the electric light mains in most of such cases in my private practice, and have had better and more rapid good results than when using the constant current of a battery. This alternating current of the mains resembles in character the discharge from an induction coil, having a rather rapidly working (100 periods per second) and smoothly vibrating contact breaker. Larger currents can be borne from the mains than from an induction coil, the curve of current in which departs more from the sinusoidal figure than is the case with the current from the mains. Hence the deep seated parts can be more thoroughly reached than with the coil, as the muscular contractions produced are less jerky, and the sensory impressions less sharp.

The physiological properties of the sinusoidal current, § 71, were first indicated by D'Arsonval, and their applications to medical treatment have been made the subject of an interesting paper by Drs. Gautier and Larat.* Among the cases there mentioned is one of obstinate sciatica of two years' duration, which yielded after five baths, although previously rebellious to all kinds of treatment, including the constant current, the interrupted current, and electrostatic sparks; and another of acute sciatica, which for six weeks had

* *Revue internationale d'électrothérapie*, vol. iii.

compelled the patient to keep his bed. He was completely relieved by the sinusoidal current baths in a week.

156. **Nervous affections.**—The debility left by influenza, which sometimes produces symptoms of considerable mental and nervous failure, is promptly relieved by the electric bath. I have had a number of these cases, and have seen them rapidly improve; the same holds good for diphtheritic paralysis. In a case of severe alcoholic neuritis recently under treatment, the patient gradually regained power in her limbs and made a good recovery, after lying helpless for several months. The return of normal electrical reactions in the muscles of the legs did not take place until some time after she became able to walk, but at the time of writing she has normal electrical reactions and good development in the muscles, which formerly showed wasting, paralysis, and a marked reaction of degeneration. Several cases which have come under treatment for injuries to the spinal cord with muscular wasting and paralysis, have also done well. A patient with a neuralgia of the descending branches of the cervical cutaneous nerves on the right side, after herpes, was cured by a short course of baths after having suffered severely for two years.

157. **Metallic poisoning.**—In patients with lead poisoning, treated by means of the bath, the results have certainly been encouraging. But among hospital patients who come in contact with lead during their work, the results are seldom very good, because they are apt to return to their occupation, and so become poisoned afresh as soon as they regain a little muscular power.

In one instance a patient with lead palsy was

treated with the battery current, and the electrodes of the bath were examined to see whether any electro-deposition of the metal could be brought about in the course of the bath. A grey deposit, which gave the proper chemical reactions of lead, was found upon the negative electrode; but it was not possible to be certain that the lead had come from the patient's tissues, for it might have been derived from lead compounds upon the surface of his body.

The removal of metallic poisons from the body by electrolysis in the electric bath has not had much attention since the time of Poey, who made a communication on the subject to the French Academy of Sciences in 1855.* In this it is stated that mercury in metallic globules had been deposited upon the negative pole of the bath in which a person was placed after a course of mercurial inunctions. It is most likely that the mercury which seems to have been properly identified by chemical tests, must have come from the surface of the skin of the patient.

Althaus refers to a case of argyrism in which a large number of baths had been tried with the object of removing the silver deposited in the patient's skin without the least success.

158. **Rickets.**—Children with rickets quickly respond to the electric bath. It is surprising to see them begin to improve in general health, and in their powers of standing and walking, and to see them gain in weight under the stimulating effect of the treatment. I have observed rapid improvement in several cases which were sent over to the electrical department at St. Bartholomew's, because their inability to walk

* Becquerel, *Traité des applications d'électricité à la thérapeutique.* Paris, 1857.

had led to the belief that infantile paralysis existed. In Italy, Dr. Sagretti and Dr. Tederchi have reported a number of cases of rickets cured by electrical treatment.

159. **Anæmia and chlorosis.**—The electric bath is not often resorted to for the treatment of these conditions, because good results can generally be obtained by simpler means. In obstinate cases where ferruginous and tonic treatment does not answer satisfactorily, the electric bath should be tried. By its use the metabolic processes of the patient can be so efficiently stimulated that increased appetite and vigour can be secured for the patient, with improved colour, and a marked gain in weight. Under these conditions the catamenia will be re-established in a proper manner. I have several times had these patients under treatment by electric baths when they were not doing well under iron, and have found that the results of general electrification are distinctly valuable.

160. **Disorders of circulation—Raynaud's disease.**—The electric bath is useful in cases of defective circulation, including those cases of local asphyxia, described as Raynaud's disease, in which the extremities often become blue and are very liable to chilblains, and sometimes even become gangrenous. The continuous or interrupted current can be employed. The patient's general nutrition and circulation will be found to have improved at the end of a course, and the tendency to chilblains will be lessened. One of the first signs of improvement in the numerous cases of infantile paralysis, which are treated by the induction coil and bath, is that the circulation in the paralysed parts is improved, the limb becomes warmer, and the chilblains disappear. The complete bath is the best, but Dr. Thomas Barlow

in his appendix to the translation of Raynaud's two *Essays on Local Asphyxia*,* recommends local arm electric baths, in the following words:—"The use of the constant current as recommended by Raynaud, has been adopted with advantage by several observers in cases of local asphyxia. The method which has been found most satisfactory by the translator, in four separate cases, has been the following:—immerse the extremity of the limb which is the subject of local asphyxia in a large basin containing salt and water; place one pole of a constant current battery on the upper part of the limb and the other in the basin, thus converting the salt and water into an electrode. Employ as many elements as the patient can comfortably bear, make and break at frequent intervals so as to get repeated moderate contractions of the limb. In a typical paroxysmal case, if the two limbs are similarly affected, it will be found that the limb which is subjected to the above treatment will more rapidly recover than the one which is simply kept warm. It will also generally be found that the patient can tolerate the above mode of stimulation much more readily than he can bear friction with the hand, and that the use of galvanism in the way indicated, or by simply 'painting' with two sponge electrodes, held on the limb at a short distance from each other, will so far diminish the pain that the patient becomes able to bear shampooing afterwards."

There can be no doubt as to the value of this measure in improving the nutrition of the limb, and in keeping the threatened gangrene at bay. Even when gangrene in the limited form, which Raynaud describes, has supervened, galvanism to the parts above and around may be tried with advantage.

* New Sydenham Society, *Selected Monographs.*

Shampooing ought certainly to be employed in conjunction with galvanism, especially in chronic cases, if the extremity of the limb undergoes a degree of atrophy, or if contractions and fibrous ankyloses take place.

If the local arm bath is used, the author would recommend that the electrode out of the water be applied to the nape of the patient's neck, so that the whole nervous supply of the arm may be in the circuit. When the complete bath is employed the induction coil will probably be found the most satisfactory. There seems to be no particular importance to be attached to the direction of the current.

161. **General conclusions.**—As a general tonic the interrupted current bath is the best. It can be used most beneficially in many conditions of debility. It is also said to be of use in alleviating the distress connected with the discontinuance of the morphia habit. Metabolism is promoted considerably. Appetite and digestion are improved. Circulation and nutrition are benefited, sleep is notably restored, and new vigour is imparted to the mental and physical faculties. In short, it is credited by all with a powerful invigorating and refreshing action upon the human frame.

It is also of value in promoting the recovery of patients after an attack of hemiplegia, the weakness of the affected parts becoming notably improved in many instances.

The constant current bath is an efficient form of treatment in chronic rheumatism, in sciatica, and in rheumatoid arthritis.

CHAPTER X.

ELECTRICAL TREATMENT IN DISEASES OF THE NERVOUS SYSTEM.

Cerebral disease. Hemiplegia. Epilepsy. Chorea. Hysteria. Hypochondriasis and neurasthenia. Insomnia. Tremors and spasm. Writer's cramp. Tetany. Exophthalmic goitre. Migraine and headache. Mental diseases.

162. **Cerebral disease.**—To obtain successful results in cases of disease of the central nervous system it is not enough to apply treatment to the peripheral parts only; the seat of the lesion producing the paralysis or other symptom must also be brought under the influence of the current if possible.

The induction coil is not so suitable for treating the brain as the constant current. In the first place the skin of the head is rather sensitive, and intolerant of all but very mild induction currents, and in the second it is not the simple stimulation of the brain which seems to be indicated so much as the "alterative" effects, and vaso-motor effects which may be set up by the battery current.

It has been said that induction currents do not penetrate the skull, and that this is the reason why applications of these currents do not give the usual evidence of stimulation of the motor cortex. This belief, however, is absurd, on physical grounds, and it has been proved experimentally that currents applied to the head do traverse the brain, and if continuous currents have been proved to do so, nothing on earth could prevent alternating currents from doing so.

Owing to the rounded shape of the head the conditions are the most favourable possible for the diffusion of current passing through it, and therefore the density of current (§§ 38 and 106) is lowered enormously as soon as the parts inside the skin are reached. The induction current becomes painful at the surface before one milliampère of current is reached, and this, though felt strongly at the point of contact of the electrode, is diffused away almost to nothing by the time it has reached the brain.

By using the sinusoidal current of an alternate current dynamo, § 71, the sensory cutaneous effects can be reduced, larger currents can be borne, and then cerebral sensations can easily be perceived. It would not be impossible to wind an induction coil in such a way as to obtain from it a current curve closely approximating to a sine curve, and with such a coil one might expect to obtain currents which could be used to influence the brain.

When the induction current is applied directly to the exposed cortex of the brain, the evidence of its action upon the nerve cells is clear. From these considerations one will see that for treating the brain the battery current is the most suitable.

The effects perceived when battery currents are caused to pass through the head, have been alluded to in § 116, they are peculiarly unpleasant at the moment of make and of break, and as a general rule sudden makes and breaks are to be avoided as much as possible in applications to the head. The patient should be warned beforehand of the sensations he will experience, and when opening or closing shocks are necessary, it is as well to give the patient a signal that he may know when to expect each. The sensation of a

flash of light produced by stimulation of the optic nerves seems to be peculiarly alarming to some patients, probably because they connect it with their previous experiences of lightning flashes. Though we must not forget Duchenne's accident when treating the brain (see § 115), we may reasonably hope not to meet with a similar disaster in our own experience.

It seems probable from a case of paralysis of both of the fifth cranial nerves, reported by Althaus,* that the sensations felt when a current traverses the skull are due to stimulation, not of the brain substance, but of the sensory nerves of the meninges; these are derived in great part from the fifth pair, and in the case referred to the sensations usually produced by the passage of electrical currents through the skull were almost entirely absent.

A fair amount of work has been done on the electrical treatment of affections of the brain, although in this, as in other branches of electrical treatment, English medical men have contributed little or nothing. Much more, however, requires to be done before the modes of application and the results produced can be firmly established.

The objects hoped for in the systematic treatment of the head in cerebral disease are as follows:—to promote the absorption of extravasated blood, to assist the circulation through the brain, to remove œdema and congestion, and to improve nutrition. All these may be classified as vascular effects, and a certain amount of evidence, partly experimental and partly clinical, has been collected, which seems to show that such vascular changes can be set up within the skull by long-continued and regular galvanic treatment. This is a promising

* *A Treatise on Medical Electricity*, by J. Althaus, London, 1870.

field for investigation. Lowenfeld has claimed that anæmia of the brain may be set up by the kathode, and hyperæmia by the anode. It has been stated that a profound effect can be produced upon the cerebral circulation reflexly by applications to the skin of remote parts; for instance, that electrical stimulation of the abdomen may set up so rapid a cerebral anæmia as to produce fainting (Liebig and Rohé). The present position of electricity in the treatment of cerebral disease is still but very imperfectly understood, nevertheless there have been a sufficient number of successful results to make the treatment very well worth a trial in every case, especially as the prospects of improvement from other modes of treatment are often slight. Even when the morbid condition itself is incurable, something may be done to relieve troublesome symptoms, such as headache, sleeplessness, mental depression and so on.

163. **Hemiplegia.**—In hemiplegia good results are sometimes obtained by electrical stimulation of the affected limbs, and this is a very valuable fact, because so little can be done in other ways to improve the condition of old hemiplegic patients. I have seen great benefit produced by the electrical treatment of such cases, and that not once or twice only, but frequently. The series of cases recorded by Prof. Erb* seems to show that after an attack of hemiplegia the muscles may remain in a crippled condition from a sort of torpor of some part of the motor tracts, so that they remain for a time beyond the control of the will, although there may be no absolute interruption in the conducting paths. Thus a patient may at once recover much of his lost power after a single vigorous electrification of

* *Electro-therapeutics.*

his affected limbs. It is therefore very important that this treatment should always be tried in cases where a patient is recovering imperfectly from hemiplegia. Treatment should not be commenced until about four weeks after the attack, in order to avoid all danger of setting up fresh changes at the seat of the lesion, and it may be repeated three or four times in the course of a week. A certain number of patients will be distinctly improved thereby. The improvement likely to be obtained in this way may be expected to show itself in the course of the first month. The further treatment may be directed to the seat of the lesion in the brain, the continuous current being employed, the anode to the forehead and the sides of the head, and the kathode to the nape of the neck, the former electrode being slowly moved to and fro (labile) without interruptions; this direction of the current has been chosen on account of its following the course of the motor tract. The current may be from one to five milliampères, and the active electrode should be of medium or large size, and should be adapted to the shape of the place on which it is applied. This treatment is to be carried out daily for four weeks, the duration of each sitting being not more than five minutes. If aphasia is associated with the hemiplegia the anode may be applied to the region of the third left frontal convolution and island of Reil. In cases of long standing it might perhaps be useful to apply the kathode rather than the anode for the sake of its stimulating effect.

164. **Epilepsy.**—This has been attacked by electrical methods, with a certain degree of success. Arthuis states that he has seen good results follow from electrostatic treatment—he considers that the treatment to be effective should be continued for some length of time,

but that it need not be pursued unless benefit is seen in the first two or three months.

Althaus says that in certain cases the continuous current may do a great deal of good. His method is "to direct the electrodes to the mastoid processes, the cervical sympathetic and those peripheral nerves in the domain of which an aura is repeatedly or occasionally experienced." He gives three cases where treatment at once diminished the frequency of the attacks, and went so far towards effecting a cure that the intervals between the fits was prolonged from a few days to two months at least. The further history of the cases remains uncertain, as they were hospital patients and ceased to attend, but as it is probable they would have returned if not cured, we may perhaps suppose that the benefit they received was permanent. The number of applications ranged from eleven to fifteen. Erb also reports that he has received a decidedly favourable impression from the treatment of epilepsy by galvanism. He advises that the anode be placed first on the side of the forehead, with the kathode to the nape of the neck, with a weak current for one minute, and secondly in the middle line of the head in front with the same current and for the same length of time, the kathode being over the occiput. The treatment of the neck and of the seat of the aura, as recommended by Althaus, should also be tried.

165. **Chorea.**—Statical electricity has been successfully tried in this disease. In 1849 Dr. Golding Bird* reported that thirty cases out of thirty-seven had been cured by electrical treatment, while five of the others were relieved. The plan of treatment was the application of sparks to the spine. The shocks from a

* *Lectures on Electricity and Galvanism*, London, 1849.

Leyden jar were found to be decidedly harmful. Dr. Golding Bird suggested that the benefit depended upon a cutaneous effect of counter irritation by the sparks.

The patient should be insulated and connected with one of the conductors of the electrical machine. An electrode consisting of a brass knob and insulated handle (fig. 55) is attached to the other conductor, and sparks applied to the spinal column and the affected limb, until a papular eruption is produced. In the case of children it is best to insulate the mother or nurse with the child in her arms, and attach them to the machine, the sparks can then be applied to the child's back and limbs as before.

In severe cases the treatment has to be repeated every day, or indeed twice a day; in less severe cases every other day or twice a week. Some patients are relieved after three or four applications of the treatment, but complete cure results after a varying time, according to the severity and duration of the attack and the frequency with which the treatment is repeated.

Writing on the same subject in the *Guy's Hospital Reports* in 1853, the late Sir William Gull gives twenty-five cases of chorea treated by statical electricity. Nineteen were cured and five improved; only one resisted the treatment. He says: "The fact stands well established that electricity is at present to be ranked amongst the means at our disposal for the cure of chorea, and that in severe cases its effects are often truly surprising. Where other means cannot be employed; when the patient is scarcely able to swallow; where the skin is abraded from the prominent bones of the emaciated frame; when the powers of life seem nearly exhausted, sparks of electricity drawn from the whole length of the spine will often, after a few repe-

titions, effect a favourable change, and enable us to administer other means of cure."

Erb proposes the use of oblique galvanisation of the head in chorea, but does not express any definite opinion as to its value. Onimus has found benefit from the application of the continuous current to the spine and the affected limbs, using ascending currents. Other writers consider that the interrupted current is probably harmful in chorea.

Some cases of chorea treated recently by electricity are recorded by Beard and Rockwell. The methods used by them were "general faradisation" or "central galvanisation," the former method being used unless the patient seemed to bear it badly. Good results appear to have followed both plans of treatment; the point of most importance insisted upon by the authors being that the currents used must be gentle and agreeable to the little patients, and that all shocks or alarms are to be avoided.

It is difficult to estimate the true value of the results obtained from the electrical treatment of chorea, because the ordinary course of the disease is so uncertain, both in its duration and its severity, and because of the tendency to natural recovery.

It is useful to employ electrical treatment in those cases which have lasted a long time, and resist the ordinary medical treatment by rest and drugs.

It often happens that patients seem to recover imperfectly from chorea, because certain habitual movements remain when the disease has otherwise disappeared. For these late symptoms electrical applications are very suitable, I have seen them quickly dispelled in several such cases by a course of electrostatic treatment with sparks. Indeed all those which I have been asked

to treat for this condition have recovered within two or three weeks.

Recent severe chorea has never come under my care for electrical treatment. I am therefore unable to support or deny the statements of Golding Bird, and others, as quoted above. The general feeling on the matter seems to be that electrical treatment might very probably aggravate the chorea by alarming the patients suffering from it. There have been no recent cases reported of cure of chorea by electrostatic methods.

The paretic states which are often left after chorea may be treated by electricity with great advantage.

166. **Hysteria.**—Hysterical affections have been very largely treated by electricity, and from the peculiar nature of the affection, good results have followed the most diverse forms of electrical treatment. The moral effect of the treatment, particularly when it is associated with sparks or with shocks, is suitable to the state of mind of hysteria, and therefore the literature of Medical Electricity, from the time of John Wesley's *Desideratum* onwards, is full of more or less wonderful cures of such cases by electricity. At the same time the value of electrical treatment lies rather in the direction of dispelling symptoms than of curing the morbid state, and it is necessary to be prepared for occasional difficulties and disappointments, even in hysterical cases, although good results will usually be obtained. We must also be careful not to claim too much for the electrical part of the treatment when it is successful, for it may happen that the touch of an electrode will cure even when there is no current. Several cases of this kind have come to my notice. Strong galvanic shocks have been used for cutting short an hysterical fit, but the most useful rôle of electricity in hysteria is for the removal of paralyses,

anæsthesiæ and spasms; for these symptoms the induction coil is most usually employed, either with an ordinary electrode or with the dry metallic brush. Statical treatment, especially the treatment by sparks, is quite as valuable in these cases, and has been very largely practised. Occasionally the continuous current is better, particularly where the complaint is of a painful point. These painful points can be successfully treated by the application of the anode, stabile, for five or ten minutes at a sitting, the commonest situations of the pain being over the vertebræ, or the sacrum, or the ovaries, or beneath the mamma. Hysterical aphonia can usually be dispelled by faradic currents applied to the throat from outside, and for the most part this method is better than the more severe application of the electrode to the fauces, or to the larynx, because the patient will not always submit to the latter method. For the hysterical condition, as distinguished from the special symptoms, it is advisable to make use of one of the methods of general treatment described in Chap. VIII., or especially the electric bath.

The electrical treatment of hysteria does not consist merely in severe applications; the treatment may be briskly applied, but pain must not be deliberately inflicted.

Another very important consideration is the diagnosis between hysteria and organic disease of some obscure kind. It is not at all uncommon for hysteria to be associated with serious disease, for instance, with phthisis; moreover, when the diagnosis has been based upon the alleged presence of a persistent localised pain in a female patient, it may after all turn out to be due to some serious latent mischief. I have known two cases where patients with early malignant disease of the

vertebræ were supposed to be suffering from hysteria alone.*

167. **Hypochondriasis and neurasthenia.** — In these conditions the methods of general electrical treatment are of great value, especially the electric bath, which answers very well to the indications for treatment required by these cases. The conditions which are now-a-days described under the general term neurasthenia, are conditions of general debility or of debility affecting chiefly the nervous system. Usually they depend upon a failure of nutrition, often started by some disturbing cause, such as mental worry or a severe illness; the digestion becomes impaired, and this keeps up the state of defective nutrition until at last the patient falls into the more or less pitiful condition which is so well known.

The mental state, which is characteristic of neurasthenics, consists in a tendency to dwell upon their symptoms, to a degree which seems unreasonable to a person in health. This makes them rather tiresome as patients. When errors in diet, extending over a long time, have at length reduced a man to a condition of neurasthenia, he may be himself quite unconscious of the cause of his illness; frequently these patients will declare that they are most careful in their food, but if the medical man has opportunities of observing them he will soon find out whether this is the case or no. Generally it is not so. Dyspepsia is almost universally present, and should be carefully attended to. The difficulty of curing neurasthenics by a few bottles of medicine also tends to make the medical man grow quickly tired of them; but indeed it is unreasonable on his part to

* Cf. Dr. Buzzard, "On the Simulation of Hysteria by Organic Disease of the Nervous System." London, 1891, J. and A. Churchill

expect a cure in that way. The only proper way of treating neurasthenics is by patience and perseverance, by enforcing a proper diet and proper rules of life, by insisting on adequate and refreshing exercise, assisted by some method of general stimulation, and it is in this capacity that general electrification serves as an useful aid. Most people tend to become neurasthenic in the slighter degrees when their daily cares exceed a certain point, and when business matters or other troubles begin to spoil the appetite, and to interfere with proper exercise and a due amount of sleep, then troubles of the neurasthenic sort begin.

To talk of one's troubles, when they crowd upon one most thickly, is natural, and to talk much of one's ailments is a habit which is seen in most chronic diseases, but it is tolerated more willingly when the patient's disease is an obvious one. It is the vagueness of the symptoms in neurasthenia which makes them seem unreasonable. It would be better if a neurasthenic could drop the minor details of his case and say to the medical man: " I am suffering from a state of chronic impairment of nutrition, with its usual train of vague symptoms, can you tell me what to do for it?"

The neurasthenic is usually a person of active mind, and the perseverance with which he tries new doctors and new remedies should not in fairness be considered a matter for reproach against him.

I have had opportunities of seeing the effect of general electrification upon a number of these cases, and I am satisfied that vigorous stimulation by the electric bath and induction coil, carried out two or three times a week, has far more effect upon neurasthenics than any other mode of treatment. Of course it should be used in conjunction with proper rules for diet and regimen,

and the original depressing cause of the disease should be found, and if possible, eliminated.

168. **Insomnia.**—Electricity frequently produces a tendency to sleepiness in patients. I have several times seen patients become drowsy while being treated. Even during the somewhat painful process for the removal of hairs by electrolysis, I have known two patients who used to become so torpid as to require rousing by engaging them in conversation. Of course if the patients are expecting the treatment to be painful they are more likely to be on the alert, but when they are not apprehensive, the manipulations of the limb or part, and the sensation of a gentle current, seem to be conducive to repose.

Treatment of the head and neck is said to be especially good for insomnia, the electric bath with the induction coil current is also useful. Larat has advised the electrostatic charge, this may be tried, either alone or in conjunction with the brush discharge to the scalp, § 101.

169. **Tremors and spasm.**—The various kinds of tonic and clonic spasm, and of tremors, come not uncommonly for electrical treatment because many of them are so difficult to relieve by any other known method. The results vary very much, as might be expected in a group of affections whose nature is very imperfectly understood, and which may arise from many different causes.

The tremors of paralysis agitans probably signify a senile or some similar failure of the motor cortex, and are not likely to be cured by electricity. The tremors of metallic poisoning are not so commonly met with as to be likely to come under electrical treatment. The electric bath, with constant current, has been proposed

as a mode of treatment for the relief of the symptoms, and for the elimination of the metal. The evidence in support of the belief that electrical currents can remove metals from the tissues is scanty, see § 157.

I have notes of three cases of tremor of the arm and hand, and one of wry neck, coming on after injury to the shoulder, one of tremors of the leg after an injury to the knee, and two of spasm and contractions of fingers after sprains of the wrist, seven cases in all, five of these were cured by a course of treatment; some by means of electrostatic sparks, others by the use of the constant current, with the anode to the affected muscles.

Tremors, and other motor symptoms affecting hemiplegic limbs, are not favourable cases. In a case of tremors of this kind in a child of eleven, in whom partial hemiplegia came on during typhoid fever, the electrical treatment of the brain is being carefully tried, but so far it has yielded no certain result. The tremor affects chiefly the flexors of the elbow, and becomes much increased when the child tries to hold something in the hand.

Hysterical tremors and spasms are also common, they do not invariably yield to electricity, though a good result may be expected in about half the cases. For them the electrostatic methods are the best, failing that, the constant current, with strong shocks through the affected parts. Two out of three cases of facial spasm were definitely arrested by electrical treatment, both were in women, aged 44 and 47 respectively. In a third patient, a man aged 30, who had suffered for three years, the treatment was of no use. Applications of the anode, stabile, are recommended.

Wry neck, from contraction of the sterno-mastoid, has been relieved five times out of eleven cases.

A patient who had clonic spasms affecting many of the muscles of the upper arm, especially those supplied by the fifth and sixth nerve roots, was completely cured by the constant current. His case is an interesting one. The movements consisted of a swinging inwards of the arm with flexion of the forearm, they were almost continuous, and had completely disabled him; he had had to give up his employment and was reduced to poverty. He had been treated for some weeks by general stimulation of the arm with induction coil currents, but these had no good effect upon him, and the treatment was suspended. He returned two months later in the same state, and it was decided, from the peculiar distribution of the affected muscles, to apply the anode over the region of the neck corresponding to Erb's motor point, in order to influence the upper cords of the brachial plexus, by setting up an anelectrotonic zone round them. Currents of fifteen milliampères were used, as this was as much as he could bear; after the first application, of ten minutes duration, it was found that the movements were temporarily arrested. It was therefore decided to continue treatment daily in the same way. After each application the patient had relief for a time, and the period of rest became gradually longer, until after two or three weeks the patient was completely cured, and has remained well since. This case is instructive in another way, for it shows that the somewhat scanty knowledge which we possess of the physiology of electric currents, may be of considerable assistance in deciding upon the mode of treatment to be selected in each case, see § 138.

It must not be forgotten that spasmodic affections are not infrequently reflex phenomena, thus there may be severe spasm of the muscles of mastication from inflam-

mation about the gums or throat, and inflamed cervical glands sometimes cause wry neck. Or there may be spasm from direct irritation of the nerves as in wry neck from disease of the cervical vertebræ. Before commencing electrical treatment a careful examination should be made for any source of irritation, and this, if possible, must be remedied.

In children, and also, though less commonly, in adults, wry neck may be due to exposure to cold or wet, and this form has been called "rheumatic," and yields easily to simple measures. Muscular spasms are also common in hysterical and emotional people, and in such they may come on quite spontaneously or as a sequel of some slight injury or illness. Apart from hysteria we often find that various forms of spasm, and especially wry neck, have been brought on by prolonged mental anxiety.

Facial spasm is not uncommon in its slighter degrees, in the form of twitchings of some of the facial muscles. Sometimes the twitchings are very frequent and severe, and though at first they can be controlled by an effort, they may in time become quite uncontrollable. The commonest form of spasm, however, is wry neck, tonic or clonic. The sterno-mastoid is usually at fault, but occasionally the wry neck is produced by contraction of the splenius capitis or the trapezius.

Very often no cause can be found for the wry neck, and perhaps it is most obstinate in these very cases. Electrical treatment has been often tried for spasmodic affections, and it is very successful in some, but fails completely in others. In hysterical cases, the dry brush or electrostatic sparks may always be tried with good prospects of improvement. In the other cases the battery current is better, the stabile action of the anode

being employed over the affected muscle and its nerves. Erb has recorded twenty cases of spasm in various muscles, almost all of which were cured by electrical treatment; a few of them improved only after a very large number of sittings, but others were very promptly cured by three or four.

170. **Writer's cramp.**—This is the best known form of a series of spasmodic affections which are produced by prolonged over-work of certain muscles, particularly when the work done is of a complicated and highly co-ordinated kind. The name of function spasms or occupation spasm has been given to this group. Besides those whose occupation is writing, violinists, piano-players, tailors and shoemakers, are subject to similar attacks in the muscles which they use most often. In writer's cramp there is a combination of muscular weakness, tremor, pain and spasm; either of these may predominate, the first and chief seat of the cramp or palsy is in the intrinsic muscles of the thumb and in the first dorsal interosseous; if the occupation be persevered with, other muscles are called in to take the place of those which are deranged, and soon they also suffer.

The characteristic feature of these affections is that the weakness, or pain, or spasm, is produced only by one particular kind of work. The hand of a man with writer's cramp remains quite useful to him for everything except for writing, and so with the other forms of occupation spasm.

It is only in advanced cases that the symptoms are provoked by other uses of the same muscles. When symptoms resembling those of writer's cramp are produced by any sort of movement involving the use of the affected muscles, some other explanation of them should

be carefully looked for, as the case may turn out not to be a true case of writer's cramp.

I have notes of twenty-six cases of writer's cramp, four occurring in women. Pain, tremor and numbness, are the symptoms most commonly complained of. Spasm is only noted in eight. The hand and forearm are the usual seat, though in one the symptoms consisted of pains confined to the shoulder, and weakness and slowness in writing. One patient gave up writing and became a maker of foot rules, but after two years of this carpentry work he found similar symptoms returning in the muscles most employed. Another patient, a woman, gave up writing and became a nurse, but a year and a half later she returned, for being out of employment she began writing again, and the writer's cramp returned. Thirteen cases are reported as cured.

Of other forms of occupation spasm I have notes of fifteen cases, four in women, their occupations are very varied, but in all there was a severe strain upon some muscles of the hand; eight are reported cured; in one, a violinist, the spasm affected the ring and little fingers, in a pianist it was the left hand which failed.

Electricity is of great value in this disease, but it must be helped by the complete abandonment for a time of the habit which has caused the development of the disease. The constant current, without sudden breaks, is to be used; currents of ten to fifteen milliampères if the patient can bear it. The skin and the electrodes to be thoroughly moistened with warm water. Different writers prefer different positions for anode and kathode, thus Dr. Poore* places the anode in the axilla,

* *Electricity in Medicine and Surgery*, 1876. *Medico-Chirurgical Transactions*, 1887.

and the kathode over the ulnar nerve just where it leaves the biceps on its way to the olecranon. The patient is also made to exercise the interossei by separating and approximating the fingers rhythmically. Another plan recommended by the same writer is to place the anode over the median nerve at the inner border of the biceps, and the kathode over the body of the flexor longus pollicis, while the patient is made to flex rhythmically the distal phalanx of his thumb. Other similar plans, including the combination of a descending current, with rhythmic exercises, may be used.

Max Weiss* in discussing the electrical treatment of writer's cramp, points out that three conditions may be found in these cases. (1) Spasms; (2) tremors; (3) paralyses; and sometimes combinations of these morbid states. In the spasmodic cases, which are usually tonic rather than clonic, on taking up the pen, the thumb, index and middle fingers, and especially the thumb and index, pass into a state of tonic spasm; the opponens pollicis and the flexor proprius pollicis and the long flexors and interossei and lumbricales all share in the spasm. The extensors are less commonly thrown into spasm, but the flexor and extensor carpi ulnaris may share it. Pronation and supination are seldom affected. Further, there are pains in the ulnar and median areas, and tender points in the arms on both anterior and posterior aspects. He considers that the disturbances are situated in the median and ulnar nerves, not in the motor cortex nor in the spinal cord. The treatment recommended is the use of constant currents of from two to five or eight milliampères, for fifteen to twenty-five minutes, with absolute rest from writing; applica-

* *Centralblatt fur die gesamm. Therap.*, April, 1891.

tions twice daily during the first weeks, afterwards diminishing to two or three times a week. Anode in the palm if extension is the main symptom, on the dorsum if flexion. Kathode to be placed on the nape of the neck, or on the upper and inner part of the arm. Anode may also be applied to the tender points for ten to twenty minutes.

Generally speaking, the anode should be employed at the seat of the symptoms, the kathode being placed centrally, over the first part of brachial plexus, or on the upper dorsal spine.

Dr. Poore's preference for a descending direction of current, is probably due to the intention of setting up the "refreshing" effect upon the nerves and muscles of the limb, § 117.

In Dr. Poore's later article on writer's cramp he has shown that a certain number of the cases have signs of some slight central lesion, either in brain or cord. There may be altered irritability in the affected muscles, and tenderness of the nerve trunks. It is possible that some neuritis may be present in some of these patients.

171. **Tetany.**—This form of spasm, although not very common, deserves mention here, because of the peculiar increase in electrical irritability which forms one of its leading symptoms. There is also, as is well known, an increased irritability of the nerves and muscles to mechanical stimulation, and this is not confined to any particular nerve, although it has been most commonly observed in the facial nerve (facial irritability). The peculiar spasms can be evoked by compression of a nerve trunk or of the main artery of a limb, or by a rough touch over a motor nerve. Erb[*] first showed

* *Arch. f. psychiatrie*, 1874.

that the electrical irritability was also increased in this disease.

In a recent paper Dr. Bernhardt* has reported three cases in which the electrical reactions were examined, his results compared with the normal irritability of the same nerves are represented in the following table, which gives the current in milliampères required to produce the first KCC contractions.

Nerve.	Normal.	Tetany. 3 Cases.
Facial	0·9—3 milliampères	0·5 —1·5 milliampères
Median . . .	0·9—3·3 ,,	0·25—1·5 ,,
Musculo spiral .	2 —5 ,,	0·25—1·0 ,,
Peroneal . . .	1 —2 ,,	0·5 —1·1 ,,

ACC and KDT (kathodal duration tetanus) were also more easily produced than usual. In the electrical treatment of tetany the influence of the anode stabile is to be directed to the affected parts, and the current must be gradually diminished at the termination of the sitting to avoid the ill effect of sudden anodal opening. The results of treatment are said to be entirely favourable, but the disease is one which tends to disappear spontaneously.

172. **Exophthalmic goitre.**—Quite a large literature has grown up on the electrical treatment of this disease, and many different methods of treating it have been recommended. Vigouroux prefers the induction coil, with the indifferent electrode on the back, and the active electrode applied successively to the eyelids, the throat,

* *Berlin Klin. Wochenschrift*, June 1891, No. 26.

the side of the neck, and the epigastrium. His method is generally preferred in France, though not exclusively so. In Germany the continuous current is preferred. Favourable cases have been reported from both kinds of treatment. So long as the pathology of the disease remains uncertain, the electrical treatment must continue to be tentative. It is by no means successful in all cases, although numerous cures have been reported in the journals.

It has been assumed that the seat of the disease is in the vaso-motor system, and especially in the cervical sympathetic. It is important to bear in mind, as has been pointed out by Dr. Gowers, that the sympathetic system is represented in the brain, and on this account the treatment should not be confined too strictly to the region of the neck.

In this country Dr. Cardew has reported* a short series of cases where the constant current produced great improvement in the symptoms. In nearly all of them the frequency of the pulse-rate was reduced as much as twenty to thirty beats per minute, the enlargement of the thyroid was greatly diminished, and the nervous condition of the patient was very much improved. He suggests that the treatment should be carried out by the patients themselves three times a day, and also at other times if the palpitation of the heart should become severe. He advises that a current of two to three milliampères should be applied for six minutes; the anode to the region of the lower cervical spine, the kathode to the side of the neck, labile, from the mastoid process to the clavicle. The two sides of the neck should be treated alternately, and the patient should persevere with the treatment for two months at

* *Lancet*, July, 1891.

least. Dr. Cardew has also proved that the diminished resistance of the body, which has been observed in this disease, is due simply to the increased perspiration and moisture of the skin.

Owing to this lowering of resistance a small electromotive force is sufficient to give the required strength of current. The number of cells in circuit must therefore be very gradually augmented, commencing with as few as three or four, and the galvanometer readings must be carefully attended to.

Good results may sometimes be obtained from general stimulation by means of the electric bath with induction coil currents.

173. **Migraine and headache.**—The results of treating migraine electrically are sometimes encouraging, and at others quite disappointing.

In severe and typical migraine there is not much use in trying to dispel an attack by electricity. In the slighter forms of one-sided headache, the pain may be immediately and permanently relieved by treatment with the constant current, the anode being applied to the seat of pain; the headaches of constipation are not usually improved in this way.

The electric breeze to the scalp has a very agreeable effect in headache, and the relief it affords is sometimes permanent, though at others it is only temporary. Cases have been reported in which a prolonged course of electrostatic charging has been followed by the disappearance of the tendency to attacks of migraine.

174. **Mental diseases.**—Some work has been done in the treatment of the insane by electricity, chiefly by means of the application of the battery current to the head. It is not impossible that general electrification by the interrupted current bath might be useful in some

of the slighter cases of melancholia, by improving the metabolic activity of the tissues. Erb's book should be consulted, both for the valuable series of references to the work done in this direction, and for an abstract of the present state of our knowledge on the subject.

CHAPTER XI.

THE NERVOUS SYSTEM. (*Continued*).

The spinal cord. Treatment of paralysis. Infantile paralysis. Progressive muscular atrophy. Injuries of nerves. Special nerve injuries. Neuritis. Nerves of special senses. Toxic paralyses. Neuralgia. Sciatica. Anæsthesia.

175. **The spinal cord.**—Treatment may be directly applied to the spinal cord by means of electrodes placed upon the back over the vertebral column. In this way currents can be made to traverse the spine in a longitudinal direction. When the effect is to be localised at one particular level the indifferent electrode should be large and placed on the front aspect of the trunk, while the other is applied to the back at the position required. Direct treatment of the cord has been carried out for the relief of certain chronic disorders, and favourable cases have been reported by Erb and others in locomotor ataxy, in concussion and other injuries of the spine, in progressive muscular atrophy, lateral sclerosis, and chronic myelitis.

The systematic electrical treatment of diseases of the cord requires very much more study before it is likely to accepted by the medical profession as a treatment of real value. In spite of the favourable cases already referred to, it is probable that the real effect of electrical treatment upon the spinal cord is still unknown. In acute myelitis electrical treatment should be avoided as it is likely to do harm.

X 2

The results of treating locomotor ataxy and progressive muscular atrophy have hitherto for the most part been negative; where locomotor ataxy has been said to have been improved or cured, the diagnosis may have been erroneous, and the symptoms may have been due to neuritis. It is important to distinguish between the statement that the results of treatment are negative, and the quite different statement that electrical treatment is useless in these complaints. It is just possible that further study may justify the belief of certain good observers that something may be done by electricity to arrest the progress of these chronic spinal cord diseases.

176. **Treatment of paralysis.** — Certain fundamental principles of treatment apply to nearly all cases of paralysis. If possible there should be treatment of the seat of disease, brain, cord, or nerves, as the case may be, and also treatment of the paralysed muscles. The seat of disease is to be treated in the hope of setting up trophic or vasomotor changes there, in order to remove the cause of the paralysis, if it be possible to do so, and the muscles are to be treated in order to maintain and stimulate their nutrition. Stimulation of the peripheral parts also acts usefully by influencing the central organs through the medium of the sensory nerves, and in a reflex manner may set up motor impulses along the nerves to the paralysed parts. When the paralysis is purely motor, and the sensory functions of the affected parts are normal, this reflex mode of stimulation is simple, and it follows that peripheral excitation of a limb in infantile paralysis, or of the face in Bell's palsy, is a rational procedure.

When a nerve trunk has been injured and repair is taking place, it is often noticed that voluntary power returns a little before the return of electrical reactions in

the nerve. Here direct treatment of the nerve trunk, by applying the electrodes to it above the seat of injury, or indirect through the agency of reflex stimulation of its centre may prove useful. Erb says:—"A hindrance in the motor conduction, which cannot be overcome by the will, may perhaps be conquered by a stronger artificial stimulation and the way thus made clear for voluntary excitation. Hence, if we allow the electric irritation to act energetically above the seat of lesion, the hindrance may perhaps be in this way removed."

When the battery current is used the paralysed muscles are to be treated by applications of the kathode, which must be well moistened and moved slowly and firmly over the affected muscles; the current to be between five and ten milliampères, and the duration of treatment ten minutes. It is important not to use electrodes which are too small. A two inch size (five centimetres) is suitable, and less painful than smaller sizes, because the density of the current at its surface is less. If five milliampères should seem to be painful in the case of a child the current must be reduced; when the skin is well wetted the painful effect of the current is diminished. In addition to the labile applications the current may be opened and closed or even reversed suddenly from time to time, for the sake of exciting contractions in the paralysed muscles. The indifferent electrode is to be placed over the spine in the neighbourhood of the central lesion.

When the induction coil is used a similar method of application may be adopted, the current must be carefully regulated so as not to produce discomfort. Or both poles may be applied to the affected part, one being buckled round the limb in a position close to the nerve trunk, while the other is manipulated over the muscles,

or lastly, both electrodes can be applied direct to the muscle. If the muscles do not respond to the coil it has been customary to use the battery current, although in such cases the induction coil may give results which are quite as good, or better. It must be remembered that the difference between the induction coil current and the battery current applied in a labile manner is only a difference in degree, one giving frequent and sudden variations of current, and the other infrequent and gradual variations. I have seen large numbers of cases with the reaction of degeneration who recovered under treatment by means of the induction coil alone.

The continually expressed opinion that for muscles showing the reaction of degeneration the induction coil is useless, is a mere belief only held by the inexperienced. The results obtained by Duchenne from induction coil currents are a sufficient proof of the value of this mode of treatment in all kinds of paralytic affections.

It is true that a muscle showing the reaction of degeneration will contract to the constant current only, and in so far as the contraction of the muscle is a good thing for the muscle, the constant current may be better than that of the induction coil; but it is absurd to think that the amount of benefit can be measured by the amount of contraction set up in the muscle. A muscle which is completely and permanently cut off from its nucleus of origin will continue to degenerate and waste, however persistently it be made to contract by treatment with the constant current. This matter of the relative advantages or virtues of constant and interrupted currents dates from a long way back. Each has been warmly advocated by its partisans to the exclusion of the other since the days of Duchenne and of Remak. See also § 139.

But in paralysis any form of electrical application is of value, chiefly if not entirely, as a means of stimulating the activity of the living tissues of the part under treatment; with the constant current of a battery the stimulation is chiefly obtained when the current is made to vary by interruptions or reversals, or by movements of the electrode over the surface, while with the coil the variations are produced by the apparatus. So far as the action of electricity upon the growth of muscle is concerned, the experiments of Debedat* are interesting, as they prove the superiority of the induction coil for stimulating the growth of muscle.

He reported the results of experiments made on the muscles of young rabbits with the various kinds of electric stimulation used in medical treatment. The experiments were made on the group of hamstring muscles; those of the left side were stimulated in various ways daily during twenty days, for four minutes a day; those of the right side were left for purposes of comparison. At the end of the period the animals were killed, and the muscles of the two sides carefully removed and weighed; portions were also hardened and examined microscopically. The modes of stimulation were as follows:—1. The induction coil current, lasting for one second, and followed by one second of interval, and so on for four minutes. 2 The battery current of 2 milliampères, with the same periods of stimulation and repose. 3. Electro-static sparks 2 to 3 millimetres long, repeated every two seconds. 4. Tetanisation of muscles for four minutes by means of an induction coil, without any intervals of repose. 5. Steady galvanic battery current for four minutes without intervals of repose. The results showed a gain of 40 per cent. in weight on the

* *Arch. d'Electricité Médicale*, February and March, 1894.

stimulated side with the rhythmic induction shocks, and of 18 per cent. with the rhythmic battery current. The effect of the static sparks was *nil;* the prolonged tetanisation caused a loss of weight; the prolonged steady battery current a slight increase in weight. Adhesions had been formed between the skin and the muscle at the points of application of the electrodes in this last. The gain in weight was due to a true growth of the muscle; the loss was accompanied by histological evidence of damage to the muscle fibres. The author concludes that the most advantageous mode of promoting the growth of muscle by electricity is to use an induction coil, and to arrange the periods of contraction and repose of the muscle so as to approximate to the conditions of a muscle during the performance of rhythmic gymnastic movements—namely, about thirty periods of contraction and thirty of rest per minute, prolonged tetanisation being distinctly hurtful.

These experiments are of great value as they indicate clearly the best method of carrying out treatment, when the nutrition of a muscle is the object desired.

Whenever children are to be treated by electricity great care must be taken not to frighten them by sudden shocks, the current used must never be so strong as to alarm them or make them cry, and it is important that the contact breaker of the coil shall work very smoothly and evenly. Many coils are defective in the matter of contact breaker; until lately there has been little attention given to it, and any sort of vibrating spring has been thought good enough, but there is a very great difference between a good and a bad one.

177. **Infantile paralysis.**—There is no doubt that electrical treatment is of the utmost value in this disease. The long lasting paralysis and atrophy which it

so often leaves behind is very discouraging, and it is only by watching and treating patients for months or years that the gradual improvement becomes perceptible. As the result of an electrical testing which has shown seriously impaired reactions, many people have been told that their children were beyond reach of treatment, although it is quite certain that prolonged electrical treatment will do good to nearly all cases of infantile paralysis, provided that not more than a year or two have gone by since the incidence of the disease. Even after that lapse of time something may be done.

The utility of electrical treatment in this disease was brought forcibly under my notice in the following way. In the Electrical Department of St. Batholomew's Hospital I found that the numbers of infantile cases in attendance was becoming unmanageable, and I thought it might perhaps be as well to discharge some of the least promising cases, but the mothers of the children were unanimous in declaring that the treatment was doing good, and they all begged to be allowed to continue attending longer. From this I thought it would be interesting to watch the cases more closely and for a longer period, in order to see whether some evidence of satisfactory progress might not be perceived. Since then I have been able to recognise the improvement, and to discharge, very considerably improved, a fair number of children who came under treatment in a more or less crippled condition.

There is a formula in which the prognosis of infantile paralysis has been commonly summed up. It is as follows:—If the ganglion cells supplying the muscle are destroyed recovery must be impossible, and if the cells are not destroyed treatment is unnecessary, because the

patients will get well of their own accord. This formula, I am sure, has done a great deal of harm, for it is widely accepted because it saves such a lot of trouble. But it starts from the assumption that the disease must either destroy all the motor cells of a muscle or else must leave them all uninjured, and this assumption is certainly not correct. On the contrary, the damage to the motor cells may be of any degree of severity or of any extent, and the paralysis may vary between slight weakness and complete loss of all motor power.

It is reasonable to suppose that a lesion in the motor tract of the cord may be limited to some of the nerve cells of the nucleus of origin of a muscle, while others in the same nucleus may escape, and this might especially be the case if the nucleus of origin is an extensive one. Although the nuclei in the anterior cornua have not yet been mapped out into groups corresponding with the muscles they supply, yet there is evidence to support the view that many of these centres extend for an appreciable distance longitudinally in the cord. Dr. Sherrington, in a paper on the lumbo-sacral plexus, clearly takes the view that some at least of the nuclei of origin in the anterior cornua may occupy an area of considerable extent, and in the plate which accompanies his paper,* he represents the nerve supply to many of the muscles of the leg as arising from the cord by fibres from two or three separate levels.

If this be so in the human subject one can readily understand how a muscle might be partly crippled by poliomyelitis and yet might retain partial voluntary power through the support of such of its ganglion cells as might happen to survive. There is also the possibility of neighbouring cells taking up the work of those

* *Journal of Physiology*, vol. xiii.

destroyed. The object of electrical treatment would then be to stimulate and develop any surviving fibres, and if possible to make them numerous enough and strong enongh to form an useful muscle.

Duchenne long ago pointed out that a muscle crippled by infantile paralysis may still contain a few living functional muscle fibres, and that these may easily be overlooked in an ordinary electrical examination of the muscle, but that they can be successfully cultivated by persevering treatment. There is no doubt that cases admitting of similar interpretation do occur, for example, I have seen a quite respectable sized mass of calf-muscle develope in a limb which for two years at least had shown no trace of electrical reaction of any sort in that region, and the same in other muscles, notably in a deltoid muscle which, after remaining for nearly three years completely atrophied as the remnant of an extensive paralysis of the upper arm, is now beginning to grow, and to show faint contractions of normal quality to the induction coil. It is an interesting point that the new development of the calf just mentioned has taken place almost entirely in the outer head of the gastrocnemius. In another case in which the deltoid was paralysed, there now is good growth in its posterior third, and there only.

If the surviving fibres can by cultivation be made numerous enough to have some useful voluntary power, they will be able to maintain themselves in a way which is impossible to them if they are unable to do any work. I have had an opportunity of testing and dissecting the muscles in an amputated leg the seat of severe infantile paralysis of old standing. The age of the patient was 20 years, and the limb had been diseased from childhood. The muscles of the leg were

all extremely atrophied, degenerated and fatty; in fact, the calf was almost like adipose tissue, but still contained a sufficient number of normal muscle fibres to make it contract fairly briskly to the induction coil current. The other muscles of the leg, though in a state of advanced atrophy, all contained fibres which were able to respond either to the induction coil or to the battery current. The intrinsic muscles of the foot were many of them normal. These reactions showed, to my mind, that even at that time there must have been some surviving ganglion cells in the affected portion of the cord, and that a certain degree of trophic nervous influence was still available for the muscles of the paralysed limb.

The persistence for several years of even a reaction of degeneration implies, I believe, that the muscles showing it are not wholly cut off from their spinal centre. When there is complete division of a nerve trunk, the muscles cease to react at all to electricity in a year or less.

Among the muscles damaged by infantile paralysis two different types exist. In one the muscles are thin, but they present reactions which though weak, are normal in quality both to the induction coil and to the battery current. In the other group the muscles are paralysed, atrophied, and show only a reaction of degeneration, or even no reaction at all.

It cannot fairly be said of the first group that they will recover spontaneously, for there are many which have failed to do so. Under treatment they usually begin to progress from the first, and do well even though the affected limb commonly remains thinner and rather weaker than its fellow.

It is well known that muscles paralysed by polio-

myelitis may recover spontaneously, but there are many others which remain in a state of very imperfect recovery, even though their electrical reactions are normal, and these derive benefit from systematic electrical treatment.

With cases of the second class, namely, those with great atrophy, paralysis and the reaction of degeneration it is also too sweeping a statement to say that they are incurable, and that electricity can do nothing for them. Electrical reactions do return in muscles which for long before have shown no signs of contraction, and this I have seen a fair number of times.

In a child with a history of paralysis having come on at the age of 4½ months, treatment commenced in June, 1891; she was then 3 years of age. There were no reactions in any muscles of either leg, there was extreme wasting, and marked talipes equino-varus in the left foot. She was quite unable to stand. After three years treatment her legs show reactions to the induction coil in very nearly all the muscles on both sides, and she can walk, though in a rather awkward manner, because of the state of one quadriceps extensor muscle, which continues very thin and weak. This child, although still feeble in her legs, has made and is still making progress, and is a clear instance of the good effect of electrical stimulation upon the nutrition of greatly enfeebled muscles, which at one time seemed to have fallen into the last degree of atrophy and paralysis.

Two similar cases of which I have notes are the following:—

F. P., æt. 5, paralysis for four years, return of normal reactions after six weeks treatment.

C. T., æt. 11, paralysis for eight years, return of normal reactions after eighteen months treatment.

The routine treatment with infantile paralysis should be as follows :—At the first visit the muscles are tested, the girth of the affected limb measured, and the voluntary power of the paralysed muscles ascertained, and any faulty attitude of the limb noted. The mother or the nurse is then instructed to carry out the electrical treatment for ten minutes daily, and she is further told to bathe and manipulate and rub the affected limbs every night for a quarter of an hour in hot water. If irons or other orthopædic appliances are worn the child is to be encouraged to exercise its limbs without them for a time every night before the evening bath. By impressing upon the parents the need for patience and perseverance, one is able to ensure their co-operation, and this is the most important factor of all. The nurse or mother must carefully be taught how to use the electrodes, and as a rule they quickly learn what is required. The induction coil is the best instrument for use in these cases. A constant battery is not suited for domestic use. The medical man must make periodical testings and examinations to see how the case progresses.

The first signs of improvement are a better circulation in the affected parts, disappearance of chilblains and sores, and a gradual gain of voluntary power.

The return of electrical reactions comes later, and it is common when all contractility has been lost for the normal reaction to the induction coil to return without an intermediate stage of contraction to galvanism only. This may mean that the few latent normal fibres in the wasted muscle have begun to grow and gain sufficient strength to produce a visible contraction.

When the lower limbs are the seat of the paralysis an improvised electric bath is a better method than

direct applications of the electrodes to the paralysed muscles. An ordinary wooden tub or earthenware foot-bath filled with warm water is taken, the electrodes in the form of plates of metal are suspended at the two ends, and the child dressed in a short waistcoat, is put into the bath in a sitting position. The current is very well borne in this way, and the whole extent of the paralysed parts comes simultaneously under treatment. This plan can easily be carried out at home daily, at the child's bed time. The strength of the current is gauged by putting the hands into the tub, one at each end, and by watching the effect upon the child, the current being weak at first, and strengthened gradually. This plan requires no special knowledge of anatomy, it is efficient and likely to be persevered in, and this point of perseverance over long periods of time is the key to success. Even if only one of the lower limbs be affected, there is no reason why the bath should not be used, and if the sound leg be flexed and drawn up, most of the electrical current can be diverted into the affected one. From Debedat's observations one would advise that the current be interrupted rhythmically at intervals of one or two seconds, see page 311.

The following summary represents the writer's views upon infantile paralysis.

It is important in every case of infantile paralysis which has lasted over four weeks to try electrical treatment, continuing it for six months or a year.

It is the exception for a muscle to be so completely destroyed by poliomyelitis as to have no functional fibres left, and these remaining fibres should be cultivated by persevering stimulation of them.

Where the muscles show only the reaction of degeneration or are even entirely abolished, some improvement may be hoped for.

Where the electrical reactions are not altered in quality, it is not good practice to leave the case to take care of itself.

In electricity we have a stimulating treatment, which is superior to any mechanical stimulation by rubbing or massage. It may advantageously be combined with these. The form of electrical stimulation to be employed is less important than the need for perseverance. As a rule the induction coil meets the requirements of the case, and either with or without the bath is quite easily arranged for use by the mother or nurse of the patient.

The distribution of the paralysis produced by acute anterior poliomyelitis is peculiar, some muscles are affected very much more commonly than others.

In the first place the lower limbs are the seat of paralysis more often by far than the upper. In the lower limb the muscles of the leg are very frequently damaged, especially the peronei, the tibialis anticus, and the calf muscles; the quadriceps extensor cruris is also rather apt to suffer; and if the paralysis affect all its parts seriously, the whole limb becomes very much crippled thereby. Except when there is extensive damage to the limb the intrinsic muscles of the foot are comparatively seldom affected, and the same can be said of those of the hand.

In the upper limb the muscles of the shoulder and arm suffer more often than those of the forearm. The deltoid is often injured, and the loss of it cripples the arm very much, and it is also a muscle which does not readily improve. Once or twice I have met with a case in which there seemed to have been two separate attacks of infantile paralysis, but this is very uncommon.

The deformities which result from the over action of muscles, when their antagonists are damaged by this disease, are well known. Many of the various forms of club-foot originate from infantile paralysis. It may be worth while to give briefly the action of the leg muscles upon the foot as summed up by Duchenne:—There are three pairs of muscles with the function of moving the foot upon the leg. 1. The calf muscles and the peroneus longus. 2. The tibialis anticus and the extensor communis digitorum. 3. The tibialis posticus and the peroneus brevis. The first pair extend the foot, the second pair flex the foot, and the last pair produce lateral movements.

The movements of flexion and extension by the first groups include lateral movements also, because the pull of the muscles is not direct. When simple flexion or simple extension movements are required, they are produced by the combined action of both components of each pair; thus, the calf muscles extend and adduct, while the peronei extend and abduct, the tibialis anticus flexes and adducts, the extensor communis digitorum flexes and abducts. Of the remaining pair, the one, the tibialis posticus, adducts, and the other, the peroneus brevis, abducts. There are many other composite movements carried out by these muscles, but individually considered their actions are those just mentioned. The special deformities likely to follow the paralysis of any of these muscles, or of any combinations of them, can be predicted, if their special action, and that of their antagonists, are borne in mind. Some of these muscles play an important part in preserving the arch of the foot, and when they are paralysed a tendency to flat foot is well marked. An opposite condition of exaggerated arch of the foot is also common, it was first

described carefully by Duchenne, under the name of *griffe pied creux*, or hollow claw foot. It is of importance in that it shows the effect of paralysis of the interossei.

These muscles flex the proximal phalanx and extend the distal phalanges of the toes by a single movement, they also produce lateral movements of the toes. Their action supplements those of the other flexors and extensors of the toes. The long flexors flex only the distal phalanges, while the extensors extend only the proximal phalanx. In the absence of the antagonising action of the interossei the long extensors extend the first phalanges permanently, and the long flexors flex the the second and third phalanges also permanently, and this produces a claw-like attitude of the toes. The abductor and flexor brevis of the great and of the little toes act in a similar way, and when they are paralysed the claw shape becomes intensified.

The hollow claw foot, though depending upon loss of power in the interossei, is not very often developed as a sequel to infantile paralysis. From their date of onset, their history, and the frequency with which the condition affects both feet, it is probable that many of the cases of hollow claw foot are due to atrophies of the interossei coming on from other causes to be considered in paragraph 192 below.

178. **Progressive muscular atrophy.**—Before entering upon the electrical treatment of this disease, it may be worth while to discriminate between the various states of muscular atrophy which have been formerly confounded under this name. These are "myelopathic" atrophies due to changes in the anterior cornua, "neuropathic" atrophies due to changes in the nerve trunks, and "myopathic" atrophies from changes limited to the muscles themselves. True progressive muscular

atrophy is a type of the first class, and pseudo-hypertrophic paralysis of the third, while various forms of atrophy due to neuritis require to be considered in the second class. Indeed the lines of demarcation between different groups have not always been drawn with precision.

In the disease known as progressive muscular atrophy, sometimes spoken of as the "Aran-Duchenne" type, electrical treatment may be employed, but the prospects of cure are not very good. Still in default of any other better method of treatment it is reasonable to believe with Dr. Gowers that the use of electricity is a step in the right direction, and seeing that patients are often very anxious to make a trial of it, it is quite right that efforts should be made to obtain alleviation of the symptoms by means of electrical treatment. Erb considers that he has seen relief, retardation, and even arrest of symptoms, especially in early cases, and advises treatment of the spinal cord, particularly the cervical enlargement, which is so frequently the seat of the most severe atrophic changes. His method is to commence with the anode to the cervical spine, and the kathode to the cervical sympathetic, followed by the kathode to the spine, and the anode to the sternum, the lumbar enlargement, or the peripheral nerves. He insists especially upon the importance of the action of both poles being brought to bear successively upon the affected regions of the cord. Finally, the affected muscles are to be treated by the induction coil current, the indifferent electrode being at the nape of the neck. The current should be "moderately strong," but too vigorous a treatment is not advisable.

Erb also says that although electrical treatment may arrest or retard the progress of the disease, that yet it is

in no way a cure, and that the curative results said to have been obtained are generally the consequence of errors of diagnosis, especially in cases of neuritis, infantile paralysis, and atrophy after joint affections. He also considers that the idiopathic muscular atrophies have a more favourable prognosis, as he has seen great benefit follow electrical treatment in long standing cases of that kind. However, Duchenne declares that by means of induction coil treatment he has been able to arrest the progress of the disease in an advanced case,* to re-establish the power of the diaphragm, which had become seriously involved, to restore the bulk and vigour of an important muscle (the biceps), to dispel the fibrillar twitchings, and that the recovery was persistent for several years, in spite of the fact that the patient returned to hard manual labour, a condition of things extremely likely in Duchenne's opinion to bring on a relapse. He is certain that he has seen increase in the bulk of a muscle from this treatment, and he says that it follows fairly often, but only in cases where the muscle had not altogether lost its irritability to induction coil currents. He lays down precise instructions for the method to be adopted as follows :—

1. To pass the moistened electrodes over the surface of each of the affected muscles, keeping them close together, and using a current of low electromotive force (primary current).

2. To stimulate the muscles moderately, and with a current which is not interrupted very frequently.

3. To treat only the muscles which react to the coil, and to pay most attention to the most important mus-

* The case, which seems to have been undoubtedly one of progressive muscular atrophy, is described and figured, *Elect. localisée*, 3rd edit., p. 500.

cles, and to terminate the sitting by a mild application to any muscles which may be threatened with an invasion of the disease.*

The views of both these authorities (Erb and Duchenne) are presented, because it might be useful to compare together a series of cases treated in each of the two ways. It may be that both writers are to a certain extent prejudiced, each in favour of his own method, but Duchenne at any rate is willing to allow that the battery current may be of use as an aid to the treatment by the coil. Erb on the other hand dismisses the latter by saying that it would only be employed in the absence of a continuous current battery. Gowers is of opinion that if regular electrical treatment be applied on one side only to a patient with progressive muscular atrophy in both arms, that no difference will be detected in the rate of wasting of the two sides. Treatment of the spinal cord itself should be carefully tried in these cases, as the mere treatment of the muscles does not appear to be very promising.

The electrical reactions in progressive muscular atrophy are a little complicated, because the gradual destruction of the muscle, fibre by fibre, produces a condition in which, while some fibres react normally, others respond only by a reaction of degeneration. It may sometimes be possible to recognise a sluggish contraction appearing after the quick contraction, the latter being produced by the sound fibres and the former by those which are degenerated.

179. **Affections of nerves.**—In injury and disease of the nerve trunks the natural tendency to recover is strong, and stimulation by electricity certainly hastens

* For the muscles most usually attacked, see Duchenne, *op. cit.*, p. 494, or Gowers' *Diseases of the Nervous System*, p. 359.

their recovery very much. It has been said of electrical treatment that the cases which do well under it would do equally well if they had been left untreated, and this has often been the excuse for the neglect of electrical methods. Even if this assertion were true, which it certainly is not, it applies with equal force to most of the drug treatments which medical men so complacently prescribe for their patients.

The following case illustrates the value of electrical treatment in a case of traumatic neuritis of the musculo-spiral nerve. A gentleman, by sitting for a long time in one position in an arm-chair, compressed the musculo-spiral nerve, and numbness and weakness of the hand, with wrist-drop, was produced. There was no treatment for several weeks, and there was no improvement. I was then asked to see him; he had paralysis with partial RD in all the extensors of the wrist and fingers; the supinator longus was also paralysed and there was impaired sensation over the back of the forearm and hand. The nerve trunk was tender to pressure at a point about half way up the humerus, corresponding to the part of the arm compressed by the chair.

Electrical treatment was commenced and at the end of a fortnight the patient had gained considerably in voluntary power and appeared to be on the high road to recovery. Electrical treatment was therefore suspended. He was instructed to rub and shampoo the limb daily, and to exercise the muscles, and was told that he might expect the process of recovery to continue, even without further electrical treatment. A fortnight later he wrote saying that he had made no progress since the last visit. Electrical treatment was accordingly resumed, and again he began to improve rapidly, and was completely well in another fortnight.

This case is related because it seems to offer satisfactory evidence that the electrical treatment played an important part in "curing" the paralysis, and because it answers the objection mentioned above, an objection which is not always easy to meet because for obvious reasons it is difficult to combat it by direct proofs.

All those who have had practical experience in the matter have seen cases of nerve injury begin to recover rapidly under electricity after having been stationary for long periods of time under "expectant" treatment.

The simplest cases of peripheral paralysis are those which follow injury to the nerve trunks. These cases are common, and are sometimes of great interest from the exercise in applied anatomy which their diagnosis affords. The shoulder and upper limb are their most frequent seat. The chief causes of injury to the nerve trunks are contusions or lacerations, compression produced in various ways, and wounds with sharp instruments. Falls or blows upon the shoulder, and dislocations of the shoulder joint commonly produce paralysis of the muscles of that region. Pressure, as from the use of crutches or from the weight of the body upon the arm during sleep, often produces paralysis of the muscles supplied by the musculo-spiral nerve, and incised wounds of the forearm and wrist often lead to paralysis of the muscles supplied by the ulnar and median nerves. In all cases of this kind electricity is of great use, both for treatment and for diagnosis; and favourable results may be expected in almost all cases unless the nerve trunks have been actually divided, or are involved in cicatricial tissue. In that case surgical measures for the union of the divided nerve, or to relieve it from its surroundings, are necessary before recovery can be expected. Indeed the behaviour of the part under elec-

trical treatment may give a clue to the diagnosis in a doubtful case, for if the electrical reactions continue to grow worse in spite of treatment, an operation for the relief of the nerve must be considered desirable.

From what has been said in §§ 131 to 134 it follows that injuries of nerves are likely to be followed by the reaction of degeneration in the muscles which they supply, and this does always follow if the injury to the nerve has been sufficiently severe. But, as such injuries may be of any degree of severity, it will be found that the reaction of degeneration is not invariably produced, for in the slighter cases the nerve recovers before degenerative changes have had time to follow, or indeed the injury may be of such a kind as to impair both motor and sensory conduction for a time without interfering with what may be called the trophic conductivity of the nerve trunk or setting up an actual neuritis. The partial reaction of degeneration is not uncommon in cases of nerve trunk injury.

In the examination of cases in which an injury to a nerve is suspected the anatomical details of the nerve supply must be carefully kept in mind.

The phenomena produced in marked cases of injury to nerves are loss of motor power, impairment or loss or perversion of sensation, and diminished temperature in the area of distribution of the nerve, with changes in the muscles, such as simple diminution of electrical excitability, or complete or partial RD, and trophic changes in the skin. The "glossy" skin of nerve trunk disease is well known, and easily recognised.

In the upper extremity the skin of the hand and fingers becomes altered in colour and livid, the finger ends become bulbous, and the nails defective. These alterations in the appearance of the skin seem to be

more marked when there is inflammatory change going on in the nerves, than when they are completely severed.

180. **The trapezius and sterno-mastoid.**—Paralysis and atrophy of these muscles follow injury to the spinal accessory nerve, and are not uncommonly seen as a result of the suppuration of strumous glands of the neck, or of the surgical operations for their removal.

Paralysis of the sterno-mastoid is easily recognised if looked for. When the head is turned towards the opposite side, the outline of the muscle standing out under the skin is plain to see in health but is lost if the muscle is paralysed.

When the trapezius is paralysed there is a general feeling of weakness about the shoulder, and complaint of myalgic pains, because the muscle plays so large a part in supporting the shoulder during the movements of the upper limb. If the trapezii be watched and studied in persons who have the neck and shoulders bare, it will be seen that these muscles are in almost continual action during movements of the arms, and, indeed, much of the beauty of the contours of the neck and shoulders depends upon the good development of the trapezii.

When one trapezius is paralysed the difference between the two shoulders can easily be recognised, particularly if the muscle be wasted as well. On the affected side the point of the shoulder is lowered, and the line from the neck to the shoulder-tip is hollowed. This difference is well seen with the arms hanging at the sides (figs. 69, 70). The position of the scapula is also changed, for the inner border of the bone does not lie parallel to the vertebral column, as in health, but at an angle with it, its upper corner being rather further from the middle line, and its lower angle rather nearer, at a

higher level and more prominent. Duchenne has explained why this is the case. The shoulder, having lost the support of the upper part of the trapezius, hangs as it were suspended by its upper angle from the levator anguli scapulæ, and turning, as on a pivot, at the point of attachment of that muscle, its lower angle is tilted

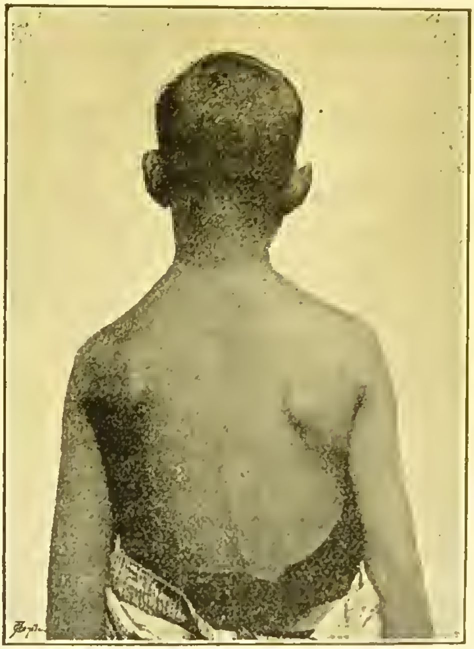

FIG. 69.—Paralysis of left trapezius.

inwards and upwards, and the acromion sinks downwards by the weight of the arm. In some cases of paralysis of the trapezius this tilting upwards of the inferior angle is not present. It may even be at a lower level on the paralysed side, particularly if the lower part of the trapezius is not completely powerless (fig. 70).

If the patient be told to raise the arms to the head another peculiar defect comes into notice; namely, that the clavicle in its outer half comes into view from behind. This is a valuable diagnostic sign of atrophy of the muscle—one which, so far as I can learn, has not previously been pointed out.

FIG. 70.—Paralysis of the upper part of the right trapezius.

I have seen four cases in which the paralysis was due to injury or section of the spinal accessory nerve during surgical operations. In the first of these the incision was a small one, high up at the posterior border of the upper part of the sternomastoid. The nerves were carefully considered during the operation, and, as was thought, had not been divided. The wound healed

very well; nevertheless, the muscle became wasted, especially in the upper and middle parts. A small band of fibres remained in the position of the clavicular portion—the *ultimum moriens* of Duchenne—but in this there was a marked reaction of degeneration. The lower part of the muscle was not quite so much atrophied as the

FIG. 71.—Paralysis of left trapezius. Clavicle seen from behind.

upper part, and the inferior angle of the scapula was not tilted upwards. In another case the whole of the side of the neck is much scarred, as the result of numerous strumous abscesses and of the surgical treatment for their relief. Both the trapezius and sternomastoid on the right side are extremely wasted, and the rhomboids are also in the same condition. The scapula and

clavicle seem inclined to fall forward by the action of the pectorals, and in that position the absence of trapezius and rhomboids becomes evident, for the contours of the ribs can be seen behind between the scapula and the spine. In spite of this extreme atrophy there still remain a few living muscular fibres in the trapezius, and it is just possible that they may in time be cultivated, so as to be of some use to the patient.

Duchenne has rather fully dealt with cases of wasting of portions only of the trapezius, and he distinguishes between the upper or respiratory portion, the middle or elevator portion, and the lower or adducting portion of the muscle. He also expresses the opinion that the upper part of the muscle will not be completely paralysed unless its nerve from the cervical plexus is damaged as well as the spinal accessory.

181. **The serratus magnus.**—Paralysis of this muscle is interesting, because the deformity which results from it is peculiar. The serratus magnus is supplied by the posterior thoracic nerve, which rises from the fifth, sixth, and seventh cervical cords, and runs down the side of the chest behind the brachial plexus to reach the muscle. The position of the nerve makes it liable to injury, especially in the side of the neck, and its independent course explains the reason why paralysis of the serratus magnus is frequently seen without any other muscle being affected at the same time. Occasionally the nerve to the rhomboids comes off as a branch from the first part of the nerve to the serratus, and therefore the rhomboids may be paralysed with the serratus magnus. In the first part of its course the nerve runs in the substance of the scalenus medius muscle.

The peculiar deformity which characterises paralysis of the serratus magnus is easily recognised if looked for.

When the patient is examined with the arms hanging down, the shoulder may seem natural, but if the patient be told to extend the arms horizontally in front of him, the posterior border of the scapula on the affected side becomes prominent, projecting like a ridge from the level of the back, fig. 72. In a healthy person the scapula

FIG. 72.—Paralysis of right serratus magnus.

remains flat and closely applied to the thorax during this movement; the function of the serratus magnus is to hold the scapula, and especially its posterior border, closely to the side of the thorax. When the arms are extended in front, the action of the deltoid tends at the same time to throw the scapula backwards, and this is resisted by the simultaneous contraction of the serratus

magnus. If the deltoid be paralysed as well as the serratus, the patient cannot extend his arm horizontally, and the deformity due to the paralysis of the serratus, cannot be brought out in the way just mentioned. In this case, if the shoulder be pushed back while the patient is told to resist, it may be found that the posterior border of the scapula can be more easily displaced on the side of the paralysis.

Paralysis of the serratus magnus is not uncommon as a result of direct injury to the nerve in the side of the neck. The following example will serve as an illustration of the usual history of such cases:—A man was using an iron bar as a lever to move heavy weights along the ground, which he did by putting the end of the bar on his shoulder, and pushing upwards forcibly against it; he felt a pain, and soon afterwards he found that his shoulder began to "grow out." When he came under observation there was marked paralysis of the right serratus magnus, and the rhomboids were also affected, which made the characteristic deformity of the shoulder even more pronounced.

In two other cases the patients had suffered severe injuries, one having been crushed in a lift accident, in which he broke his forearm, and the other having been hurt by a heavy packing case, which fell upon him. Both of these, in addition to other injuries, had paralysis of one serratus magnus—the right. Indeed, all the cases of paralysis of the serratus magnus from injury which I have seen have been on the right side, and in male patients.

The notion is sometimes entertained that the peculiar position of the shoulder-blade described above is due to dislocation of the latissimus dorsi from its position at the angle of the scapula. This view is erroneous.

182. **The rhomboids.**—These are supplied by a special nerve, which comes off from the fifth and sixth roots. In common with the other muscles, whose nerves run a somewhat exposed course in the neck and shoulder, the rhomboids are liable to paralysis from injury. It is not usual to find them paralysed alone. When they are paralysed the posterior border of the scapula is less firmly placed than in health, and the fingers can be introduced under the edge of the bone more easily than usual. If the trapezius be well developed, it is not very easy to make out the paralysis of the subjacent rhomboids by electrical testing.

183. **The scapular muscles.**—The supra- and infra-spinati are often paralysed, as the result of blows upon the shoulder, though less frequently than the deltoid.

When the spinati are wasted, the spine of the scapula becomes prominent, and the muscles themselves can be seen to be diminished in bulk. The patient is unable to perform external rotation of the humerus in a proper manner if the infra-spinatus is paralysed; and the other external rotator of the humerus, the teres minor, is often affected simultaneously though supplied by a different nerve. The movement of external rotation is necessary in writing for moving the hand across the page, and in sewing the same muscles also come into play.

The nerve (supra-scapular nerve) which supplies the spinati is exposed to the risk of injury, owing to its superficial position on the shoulder. The supra-spinatus is a much less important muscle than the infra-spinatus, and its condition is not so easy to determine, because it is thickly covered by the trapezius, which makes electrical testing of the muscle difficult, and its functions as an elevator and a weak internal

rotator of the humerus can be completely performed by the other muscles. When the infra-spinatus is paralysed, it is usually extremely probable that the supra-spinatus is in the same condition.

The internal rotators of the humerus, namely, the the sub-scapularis and teres major, have a nerve supply (the sub-scapular nerves), which escapes injury much more often than the spinati ; and the same may be said of the latissimus dorsi, also supplied by a similar nerve—the long sub-scapular.

These muscles frequently escape, even in very severe injuries of the shoulder; the pectoralis major and minor also escape as a rule. Thus I have seen a patient with complete paralysis of all the muscles supplied by the brachial plexus, except the internal rotators, the latissimus dorsi, and pectorals, and similar cases are not very uncommon, especially after serious dislocations of the humerus.

184. **The deltoid.**—Paralysis of this muscle from injury or dislocation of the shoulder-joint is one of the most common forms of paralysis in the upper extremity.

The circumflex nerve is exposed to injury in its course through the muscle, and its trunk may also be strained in dislocations, or it may be compressed by a crutch or axillary pad. The teres minor suffers with the deltoid when the injury is to the trunk of the nerve; when the injury is in the intra-muscular part it may escape. It is not always easy to determine the state of the teres minor by electrical testing, as it is so much covered by other muscles, nor by observing the voluntary movements of the patient, as its functions can be adequately performed by the infra-spinatus. The attempt to ascertain its condition, however, should always be made.

The spinati are often paralysed by the injury which paralyses the deltoid.

The flattened appearance of the shoulder, and the prominence of the acromial process of the scapula make it easy to recognise paralysis of the deltoid, unless the

FIG. 73.—Paralysis of right deltoid.

subject be very stout. In infants also the adipose tissue which covers the shoulder may mask the wasting of the muscle. When the wasting and paralysis are extreme the head of the humerus is no longer held up in the glenoid cavity, but can be seen and felt to hang loosely

in a state of partial dislocation, and to be freely moveable in its socket. One may even be able to push the tip of a finger between the acromion and the head of the humerus. In cases of paralysis of the deltoid it is not uncommon to find some adhesions or creaking in the shoulder-joint; for an injury of the circumflex nerve may produce paralysis of the muscle and changes in the articular surfaces. In examining a patient who complains of weakness in the shoulder it is useful to bear this in mind, and to test the condition of the deltoid, for otherwise one may regard the case as one of primary arthritis of the joint when the articular mischief is in reality secondary to injury or disease of the circumflex nerve.

When the deltoid is paralysed the arm cannot be raised to the horizontal position, and the utility of the limb is very seriously diminished for a very large number of movements, as there is no other muscle able to supplement it to any appreciable extent; the supraspinatus has a similar function to the deltoid, but it is too feeble to be able to raise the weight of the arm. It sometimes happens that part only of the deltoid is paralysed; I have notes of three cases. In one the patient had had suppuration round the shoulder, and an incision for the evacuation of the pus was made on the posterior aspect of the joint. One of the branches of the circumflex nerve was injured, and the posterior half of the muscle was wasted, and showed a partial reaction of degeneration. Under electrical treatment combined with daily rubbing the muscle recovered.

The deltoid is rather apt to suffer in infantile paralysis of the upper limb, and the chances of its recovery in this disease are not good. I have known a paralysis of this muscle persist as the remnant of an extensive

paralysis of the whole upper limb, and in other cases have found it most difficult to arouse any new growth of muscle-fibres in the deltoid, even after months of persevering electrical treatment. This may mean that the nucleus of origin of the fibres which supply the deltoid is a small circumscribed one, or that the muscle, working as it does at great mechanical disadvantage, cannot afford the loss even of a portion of its fibres without serious impairment of its powers.

In one of my infantile cases the posterior third of the deltoid has grown again under treatment into a fairly strong muscular bundle, the rest of the muscle remaining quite wasted.

In the ordinary traumatic paralysis of the deltoid the prognosis is more favourable. The majority of the cases recover, but there is a considerable minority which do not, and on this account it is wise to express a guarded opinion when there is much wasting and a reaction of degeneration, and the prognosis must be made to depend upon the behaviour of the muscle under treatment. If the electrical reactions are normal, or show only a quantitative change, or the partial reaction of degeneration, the prognosis is more favourable. Taken generally, the deltoid may be said to be a muscle which is easily damaged, and has not a very great recuperative power. The presence of articular changes in a case of paralysis of the deltoid is unfavourable, though here also recovery may take place. The skin over the deltoid receives sensory fibres from the circumflex nerve, and impairment of sensation or anæsthesia is frequently to be found if looked for when the muscle is paralysed.

185. **Combined paralyses of the upper limb.**—It often happens that many of the muscles of the arm

are paralysed together from injury or disease of the nerve-trunks. After a serious dislocation of the shoulder, and particularly if this has remained for some hours unreduced, there may be complete paralysis of the whole limb. Mr. Bowlby has published* several cases in which the injury caused rupture of all the roots of the brachial plexus, but this is not a usual result of injuries or dislocations of the shoulder. When the roots are torn out of the spinal cord there may be laceration of the fibres destined to emerge from the thoracic cord to supply the cervical sympathetic, and the pupil on the injured side may be contracted in consequence. Several cases have been reported in which this has been observed.

Several causes combine to produce extensive paralysis after a dislocation. The head of the humerus presses upon the brachial plexus in dislocations forward below the coracoid process, and so produces paralysis below that point ; but this pressure will not cause paralysis of the muscles of the scapula, for these are supplied by branches given off higher up, and yet they are generally, if not always, implicated. It is possible that the upper cords of the plexus may be compressed between the clavicle and the vertebral column if the violence has tended to drive the shoulder backwards, for the shoulder has free play from the sterno-clavicular joint, and might be driven sufficiently far back to produce such compression. Or the upper cords of the plexus may be more directly subjected to traction from the injury, or finally they may be damaged by the efforts employed in reducing the dislocation, and from their position and direction they are more likely than the lower roots of the plexus to suffer in this way.

* *Injuries and Diseases of Nerves*, London, 1889, J. & A. Churchill.

It seems probable that the upper cords of the plexus are most likely to be injured by traction, either in the injury or in the efforts to reduce the dislocation; while the nerve-trunks of the arm are injured lower down by the pressure of the head of the bone against them. The subscapular nerves by their position, and by the direction in which they run, are rather better protected than the other nerves from both these accidents; and this perhaps accounts for the frequent escape of the latissimus dorsi, the subscapularis, and the teres major muscles in extensive paralysis of the shoulder and arm from injury.

186. **Erb's paralysis.**—One particular type of combined paralysis affecting the muscles of the shoulder and arm has received this name, though in France it is often known as the Duchenne-Erb type, because Duchenne first drew attention to it, and reported five examples. He was unable to explain the peculiar association of certain muscles in these cases, and it was Erb who, in 1874, pointed out the anatomical reasons for this special grouping. The affected muscles are the biceps coraco-brachialis and brachialis anticus, which are supplied by the musculo-cutaneous nerve; the deltoid (circumflex nerve), and one muscle supplied by the musculo-spiral, namely, the supinator longus; often the spinati too (supra-scapular nerve) are involved. The affection of the supinator longus alone among the muscles supplied by the musculo-spiral nerve seems at first to be a perplexing feature, but it suggests the idea that the injury must be situated above the point at which the musculo-spiral nerve is built up. Erb pointed out that an injury limited to the two upper roots of the brachial plexus, the fifth and sixth cervical, or their combined trunk, would produce the kind of paralysis

under consideration; and further showed that these cords can be directly stimulated at a point in the neck one inch above the clavicle and a little external to the outer border of the sterno-mastoid. This is known as Erb's motor point, and by means of an electrode applied to it the muscles in question can be readily thrown into simultaneous contraction (§ 125).

The existence of Erb's paralysis as a clinical unit depends upon the comparatively exposed position of these two nerve roots, just as we have seen that paralysis of some of the single muscles of the shoulder are common for the same reason, and varieties in the extent of the paralysis exist according as the injury or disease affects chiefly the fifth or the sixth roots or their united trunk.

From the investigations of Ferrier, Herringham (§ 126) and others we have a fair knowledge of the levels at which the different components of the nerves of the upper limb leave the spinal cord. There is a certain amount of variation between individual cases, so that we cannot state absolutely that certain fibres run always in the fifth root, and certain others only in the sixth or seventh. Moreover, many muscles receive their nerve-supply from more than one level; for example, the serratus magnus from the fifth, sixth, and seventh cervical roots.

From what is known one would expect that a lesion of the fifth and sixth roots, or of their combined trunk, should involve not only the muscles already mentioned, but also the rhomboids, the teres minor, the subclavius, and the upper parts of the pectoralis major and serratus magnus, and the supinator brevis, and most of these muscles have been noted as involved in some of the recorded cases.

Although a large number of cases of this form of paralysis have been collected, it is not in all of them that a sufficiently minute examination of the implicated muscles has been made. Further study of these cases, if carried out with proper care, is likely to advance our knowledge of the anatomical distribution of the fibres emerging at the upper levels of the brachial plexus.

It must be borne in mind that Erb's paralysis is not in the least a special form of disease. The name has the advantage of brevity alone. Any sort of injury or disease which is limited to the upper part of the brachial plexus will produce paralysis of the group of shoulder and arm muscles already mentioned. In particular, injury to the child arising during difficult labour is a common cause, so that Duchenne described it as "obstetrical" palsy of the arm. Among twenty cases of which I have notes, seven were caused in this way, four followed injury, and one was due to sarcoma of the cervical vertebræ, though, from extension of the disease, the paralysis was not long limited to the muscles of the Duchenne-Erb group. One was associated with an abscess in the neck, and the remainder came on gradually and were due to neuritis of some kind.

All degrees of combined paralysis from the typical Duchenne-Erb type to complete paralysis of the shoulder and arm may be met with.

I have seen one case, typical in other ways, in which the deltoid was at no time affected, though the supinator longus and the three flexors were.

The triceps in some cases, and the extensors of the wrist in others, have been noted to be weak in cases of Erb's paralysis. In two cases I have seen some weakness of the upper part of the pectoralis major.

Infantile paralysis may sometimes resemble Erb's

paralysis in its distribution, but it is not likely often to be confounded with it if the history of the case and the distribution of the paralysis be carefully taken into account. Fig 74 is from a case of infantile paralysis, and shows wasting of the deltoid, spinati, and trapezius, the last only in its upper part.

FIG. 74.—Paralysis of trapezius, spinati and deltoid on right side.

187. **The nerve trunks of the arm and forearm.**—The musculo-spiral, the median, and the ulnar nerves are often injured in their course in the arm and forearm. The usual causes are pressure, including pressure from

bandages or splints too tightly applied, incised wounds, implication in callus or scar tissue, and contusions. Pressure palsies affect more especially the musculo-spiral in the upper arm; while the ulnar and median suffer more particularly from incised wounds, and in the forearm. Paralysis from the pressure of splints and bandages is sufficiently common to be of importance, and though fortunately it is not usual for injury produced in this way to cause permanent harm, yet sometimes it does do so. I have notes of a case in which the ulnar muscles were almost totally atrophied as the result of bandaging, and I have seen quite a considerable number of cases in which there was little or no doubt that the bandaging had been the cause of paralysis. Thus in one patient who received an incised wound involving the median and ulnar trunks it was found, when the wound had healed, that he had developed a paralysis of the musculo-spiral as well. I have little doubt that many of the cases of so-called "reflex paralysis" have been due to injuries from splints and bandages.

188. **The musculo-spiral nerve.**—Paralysis of the muscles supplied by this nerve is characterised by the presence of wrist-drop; usually the extensors of the wrist and fingers and the supinator longus and brevis are involved; the triceps may either escape or may be involved according as the injury is high up in the arm or not.

Musculo-spiral paralysis from pressure on the trunk of the nerve during sleep is extremely common, at least among hospital patients.

The usual history is that the patient, having had too much to drink, goes off into a heavy sleep, from which he awakes with his hand and forearm powerless. Often

the patient has slept while sitting at a table with the head resting on the arm, or with the arm hanging over the back of a chair; in either case the musculo-spiral nerve-trunk has been pressed upon. Almost always the patient has been under the influence of alcohol and has slept very soundly. Otherwise the discomfort felt in the arm would have been likely to awake him before the production of more than a transient paralysis. The predisposing effect of intemperance is well shown in the following case:—A potman after sleeping for two or three hours developed a pressure palsy of his left musculo-spiral nerve. This got better, but in the following year he injured his ankle and was obliged to use a crutch. This brought on another attack of musculo-spiral palsy before he had used the crutch more than ten days.

Slight degrees of temporary paralysis from pressure on a nerve-trunk during sleep are familiar to most persons. To notice a numbness or a feeling of pins and needles in one arm on awakening from sleep is not uncommon, especially among those who are not in vigorous health.

Paralysis from pressure has been thought to be secondary to compression of the blood-vessels of the limb, producing anæmia of the nerve, but if this were the case the paralysis should not be confined to the region of one particular nerve-trunk, as is the rule. It would rather be expected to involve chiefly the distal parts, irrespective of the nerve-supply if it were due simply to anæmia of the limb from compression of the main artery.

A case which came under my observation some years ago of a pressure palsy in the leg shows that it is the nerve itself which suffers from compression. In that

case the pressure was on the great sciatic nerve at the back of the thigh, and there could not have been any compression of the femoral artery. The patient was a young man who attended a meeting, and in order to have a better view of the proceedings he sat for an hour upon the back rail of his chair; at the close of the meeting he found his leg numb and helpless, and was assisted home. Two days later he came under observation. He had paralysis of all the muscles below the knee. He recovered in a fortnight under treatment by rubbing and the induction coil current.

Sleep palsies are almost always limited to the musculo-spiral nerve. The circumflex nerve, the ulnar, or the upper roots (Erb's paralysis) may be affected when the patient has slept in a very awkward attitude.

In crutch palsy too it is usually the musculo-spiral nerve alone which is paralysed, but the circumflex nerve, or the ulnar or median may also be involved. Sleep palsies are always unilateral; crutch palsies may be double if two crutches are used, but they are usually more marked on the side of the weakest leg.

The degree of impairment of sensation varies much; as a rule there is some complaint of numbness on the back of the forearm and hand, and some anæsthesia may be detected. The methods for testing cutaneous sensibility are not very good, and it is not easy to arrive at results without considerable trouble. Weak induction currents are useful, but it is not possible to distinguish between analgesia and tactile anæsthesia by their means (see § 136).

Pressure palsies vary considerably in severity. Those in which the electrical reactions are not much impaired may recover in ten days or a fortnight. When the reaction of degeneration is present the duration will be

longer. Recovery can be confidently expected in uncomplicated cases, where the pressure has not lasted very long, and it is certainly promoted by electrical treatment. I have often seen improvement start at once on the commencement of electrical treatment, after weeks had been wasted in vain in the expectation of spontaneous recovery. It is probable, however, that even in these the paralysis would go away of itself in time, but this does not prove that electrical treatment is unnecessary.

When the pressure is due to the use of crutches they must either be given up, or if that is impossible the head of the crutch must be well padded; crutches with handles which can be grasped by the hands are the best, for with them the patient can transfer part of his weight from the arm-pits to the wrists.

The other common affection of the musculo-spiral nerve, namely, lead poisoning, will be dealt with in a succeeding paragraph.

189. **The ulnar and median nerves.**—These nerves are frequently divided at or near the wrist by incised wounds; a very large number of the cases being from cuts caused by broken glass. It is not uncommon for both nerves to be divided in one accident, and if the ends are not re-united when the wound is first dressed, serious impairment of the power of using the fingers is the result.

When the ulnar nerve has been completely divided near the wrist the symptoms produced are:—1. Paralysis with wasting and the reaction of degeneration in the hypothenar eminence, in all the interossei, in the two ulnar lumbricales, and in the adductor and flexor brevis (inner head) of the thumb. After a time the deformity known as the "clawed hand" is produced. The

palm becomes thin and flat, the heads of the metacarpal bones become unduly prominent, the proximal phalanges are over-extended, the distal phalanges are permanently flexed. This is the result of the paralysis of the interossei. It has already been shown (§ 177) that in the foot the action of the long flexors of the toes is to flex the distal phalanges only, and that of the long extensors is to extend the proximal phalanges, and that when the interossei are paralysed the clawed attitude of the toes is produced in consequence. The mechanism is the same in the case of the hand, the interossei flex the proximal phalanges and extend the distal ones; and so supplement the movements of the fingers which are performed by the long flexors and extensors. 2. There is loss of sensation in the little finger, in the ulnar half of the ring finger both front and back, and in the corresponding part of the palm and the dorsum of the hand. 3. Trophic changes are produced in the skin and finger nails of the anæsthetic area, often with œdema; the temperature of the part is lowered, and sometimes there is very severe pain of a burning character, to which the name of "causalgia" has been given, this is not very common, nor is it usually present when the nerve has been completely divided. When it exists the temperature is raised above that of the opposite side, and the patient experiences a sensation of heat, and seeks for relief by cold applications.

After division of the median nerve at the wrist the conditions are different, the clawed hand which is so characteristic of the divided ulnar nerve is not present, and the chief feature is the wasting of the thenar eminence, and the everted or ape-like thumb, which lies with the nail facing dorsally; the abductor, opponens and outer head of the flexor brevis of the thumb are para-

lysed, atrophied, and show the reaction of degeneration. There is loss of sensation in the thumb, index, middle, and half the ring fingers, and in the corresponding part of the palm, and of the two distal phalanges of the same fingers on the dorsum of the hand.

190. **The lower limb.**—Paralysis from injury is much less common in the leg than in the arm. I have notes of only a few instances. In one interesting case* there was paralysis of the front leg muscles from the pressure of a leather pad upon the peroneal nerve just below the head of the fibula. The patient was a man who walked daily upon stilts which were strapped to the legs, and so set up the pressure upon the nerve.

Other cases have followed injury about the knee-joint, or a fracture through the lower third of the femur, and one was after an operation for the relief of genu valgum. The most usual seat of the injury to the nerve trunks of the lower extremity is in the external popliteal nerve or the peroneal nerve. Bowlby† mentions several cases of paralysis of these trunks complicating fractures, and has also seen two cases of injury to the peroneal nerves after osteotomy for genu valgum.

191. **Neuritis.**—This occurs very commonly as a cause of paralysis apart from traumatic causes.

The clinical importance of neuritis is much more clearly recognised to-day than it was a few years ago, although Remak in 1860 wrote "I am convinced that medical practitioners will soon recognise that neuritis is a pathological condition which occurs more frequently than is usually believed."

One of the most troublesome forms of neuritis is that which occurs in a part which has been the seat of sup-

* *Arch. d'électricité médicale*, 1894.

† *Injuries and Diseases of Nerves.* London, J. & A. Churchill, 1889.

purative inflammation, and is not uncommon after poisoned wounds of the hand. The crippled condition which is produced in these cases, though largely due to a matting together of the ligaments and tendons, presents also well marked signs of neuritis. It is sometimes difficult to settle the question whether nerves may not have been divided in the incisions necessary for the evacuation of abscesses in these cases, and electrical testing is sometimes appealed to for an answer. As the neuritis is essentially one affecting the peripheral branches of the nerves in the involved part, it is sometimes possible to obtain reactions which show that the main nerve-trunks are intact, for instance in the case of the hand, the most frequent seat of this kind of neuritis, certain of the ulnar or median muscles may have suffered less than their neighbours, and by their reactions may show that the main nerve-trunks have not been divided. It is difficult to decide how far in these cases the neuritis is due to the inflammatory mischief, and how far to a secondary compression by cicatricial tissue, but there is evidence to show that a true neuritis is present and that it may extend along the nerve-trunks beyond the area in which it would be subject to compression.

Neuritis coming on in the course of some acute disease, or as a sequela thereto, is often the subject of electrical treatment. I have notes of several cases of local neuritis of this kind, for example of the nerve to the serratus magnus, of the circumflex nerve, and of the fifth and sixth cervical roots (Erb's type), all coming on after typhoid fever. One patient after an attack of erysipelas suffered from pain in the shoulder and elbow of one side, supposed at first to be rheumatism, but which turned out to be a neuritis affecting the supra-

scapular and circumflex nerves, and the ulnar nerve. There was a good deal of pain, followed by complete paralysis and wasting, with RD in the affected muscles. In another case mentioned to me a gentleman had extreme wasting of one gluteal region after influenza.

The paralysis which follows diphtheria is probably due to neuritis, though this is not quite settled. Generally the electrical reactions are not seriously altered in cases of diphtheritic paralysis, and they recover spontaneously. The reaction of degeneration may be present however. In the cases which have come under electrical treatment the applications have certainly appeared to have been of service in hastening recovery.

Neuritis is sometimes met with in syphilis, the following is a striking example. A man came under treatment in December, 1892, with a paretic condition of the right arm. There was marked wasting of the biceps, and the grasp of the hand was much diminished in power. He had pains, felt chiefly to the inner side of the arm. On the chest there was an indolent tertiary skin affection.

In two months he recovered, but after a few months he returned again with sciatica, and soon after this had left him he was attacked with a similar condition of the other sciatic nerve. Finally, eighteen months after his first appearance he again presented himself, this time with facial paralysis. The clue to his case was given by the ulceration of the chest-wall when he came first under treatment. His attendance being irregular he has now disappeared from view. The facial paralysis was not improved when he was last seen.

Neuritis coming on from exposure to cold *(paralysis a frigore)* and "rheumatic" neuritis form a group of cases often spoken of. It is not possible to deny that cold or

rheumatism may cause neuritis, but there is no doubt that many of the cases are put down to these causes for want of more precise knowledge concerning them. In the commonest of these paralyses, that of the facial nerve, a cold wind or draught blowing on the face is often referred to as the exciting cause (see § 195).

True peripheral neuritis coming on without obvious cause, and sometimes attacking several members of a family in succession is one of the most interesting subjects in the whole range of nervous diseases. The cases described by Tooth under the title of the "Peroneal Type of Muscular Atrophy," and those cases described by myself of symmetrical atrophy of the hands in young people* are almost certainly of this kind.

192. **Pes cavus.**—It is probable too that some of the perplexing cases of double pes cavus which are met with from time to time are due to a peripheral neuritis, involving the interossei of the feet. Pes cavus with clawing of the toes is often present in the various diseases which lead to muscular atrophy; it can only be produced by weakness of the interosseal muscles, and although some of the cases do probably follow from infantile paralysis, this is not in my opinion the commonest cause. The history of a gradual onset, the frequency with which it affects both feet, and the time of life (adolescence) at which it most often appears, are against the view that it is a condition due chiefly to infantile paralysis. In determining whether a muscular atrophy is due to a primary affection of the muscle itself, or is secondary to a change in the spinal cord or the nerve trunks, it is customary to attach much importance to the results of electrical testing, the presence of a reaction of degeneration being taken to signify a

* *St. Bartholomew's Hospital Reports*, 1893.

nervous lesion, while in the primary myopathies the reactions are normal in quality until they disappear altogether. Using this test in cases of pes cavus I have found that the reactions of the interossei are not as a rule normal, nor on the other hand do they commonly show a reaction of degeneration; usually it is found that one or two of the interossei may react naturally, while in the others no response can be elicited; in other cases none of the interossei can be made to contract at all. The testing of the dorsal interossei of the feet is not very easy in normal individuals; the third being as a rule more difficult to throw into contraction than the others. Sometimes I have noticed a remarkable simple diminution without RD, but with greatly decreased cutaneous sensibility to the coil current in cases of pes cavus, notably in a family of five persons, all with both feet affected. In these the reactions were obtained with the greatest difficulty and only with very strong currents which were hardly felt by the patients tested.

In my experience the intrinsic muscles of the feet escape in infantile paralysis in by far the greater number of cases, even when the leg muscles are extensively paralysed, and Sherrington's experimental work upon the monkey seems to show that the leg muscles derive their nerve-supply from a higher level in the cord than that from which the interossei are innervated.

There is still much work to be done in the field of muscular atrophy to separate the cases due to primary change in the muscles from those in which the wasting is secondary to changes in the nerves. The results of electrical treatment are not favourable, though I have reported in the paper just quoted a case of atrophy of the intrinsic muscles of the hands, which recovered.

The reactions in neuritis vary between complete RD

on the one hand and simple diminution on the other, according to the severity of the disease. It is important in testing to employ both the induction coil and the battery currents. If only the former be used cases of partial RD are likely to be overlooked, and partial RD is very common in cases of neuritis.

The treatment is that already described under the heading of the treatment of paralysis. Good results will usually follow from the use of the induction coil current, and with this may be combined the continuous current applied in a labile manner. The induction coil is contra-indicated if its use increases the sensation of pain in the affected parts.

Dr. Cagney* in a recent paper has strongly advocated the use of the constant current even in acute neuritis, declaring that there is no risk of doing harm by this mode of treatment.

When the neuritis is general, general electrification by means of the bath is the most suitable method, and when it is local then local applications to the affected nerve and muscles are to be preferred.

193. **Toxic paralyses.**—The neuritis produced by alcohol and by lead come often under electrical treatment, arsenical neuritis is much less common, but in the distribution of the resulting paralysis it closely resembles the alcoholic form, the extensors of the feet being much affected. If the alcohol can be withdrawn, cases of neuritis due to this cause respond well to electricity. Thus I have notes of a patient who after lying helpless for months began immediately to improve under treatment by means of the bath and induction coil, until at the present time she has recovered good voluntary power, has well nourished muscles, normal

* *The Clinical Journal*, Feb. 20th, 1895.

reactions and good knee-jerks, although both these had been for a long time completely lost.

194. **Lead palsy.**—In paralysis due to lead the reaction of degeneration is usually present, in fact it is an early symptom, and, as has been shown (§ 135), it may precede the paralysis. The partial reaction of degeneration is often present in some of the affected muscles, and others may show only simple diminution to both forms of current. Erb has stated that from the long duration of lead paralysis and the frequently occurring relapses, the condition of the electrical excitability may be considerably complicated. Treatment by electricity is of great value, muscles which have lost their electrical irritability almost completely may be seen to recover it under this treatment, which must be long continued to obtain good results. The value of the induction coil current in this disease must not be forgotten. Although more recent writers advise the constant current almost exclusively, the experiences of Duchenne long ago showed that something can be done by coil currents also. He writes that in lead palsy recovery will follow the treatment "almost always," even if the irritability to the induction coil current has completely disappeared from the muscles. His method is to use a strong current, with rapid interruptions, for ten minutes; the treatment should not be prolonged beyond that time lest fatigue and pain be produced.

Distinct improvement will often be found after ten or twenty sittings, even if the affection is of old standing. The deltoid when affected recovers quickly, and the radial extensors do so more quickly than the ulnar. To determine which of the extensors of the wrist are affected, the patient is told to raise the forearms and pronate them. If the muscles are all three of them para-

lysed there is then no power of extending the wrist at all. If the extensor carpi radialis brevior can act, extension of the wrist is possible when the fingers are first flexed. If only the extensor carpi radialis longior, or the extensor carpi ulnaris, can act, then slight extension is associated with a lateral movement to the side of the acting muscle. Although the supinator longus usually escapes in wrist drop due to lead, it may be paralysed. The blue line on the gums may be absent in lead poisoning. The wrist drop usually affects both sides. Treatment by means of a general bath, or of an arm bath, is often convenient, for the latter a tub should be chosen which will receive both arms from the elbow downwards; the two limbs are then immersed and the current passed between electrodes placed at the two ends of the bath.

It is extremely important when the lead poisoning is a result of the patient's occupation that he should be advised to give it up altogether, otherwise relapses are almost certain to follow his return to work. When the patient returns to his occupation partly cured, he is almost certain to relapse.

195. **Facial Paralysis.**—This is a common form of paralysis, and very frequently comes under electrical treatment.

If we except those cases of paralysis of the facial muscles which form part of hemiplegia the remainder usually depend upon disease of the nerve trunk or of its nucleus of origin, and of these the commonest seat is in the nerve-trunk, and the part of the nerve which is usually at fault is that which passes along the Fallopian aqueduct.

In this part a very little swelling of the nerve or of the walls of the aqueduct is sufficient to cause com-

pression of the nerve fibres. Disease of the ear and exposure to cold are the commonest exciting causes.

The reaction of degeneration is present in a large number of cases of facial palsy, and a case carefully watched and treated from the commencement offers one of the best introductions to the subject of electrical diagnosis and therapeutics, and the disease has been much studied from this point of view. The phenomena of the reaction of degeneration were first observed by Baierlacher in cases of facial palsy (see § 130). In all but the slight cases the reaction to the induction coil disappears within the first week. If the patient is tested daily, the gradual development of the RD, will be clearly seen. In testing the muscles it is well to bear in mind that the skin of the face is sensitive, and the muscles are near the surface, strong currents are therefore unnecessary, and must be avoided. For the importance of the electrical reactions in prognosis, see § 134. Even in the worst cases of facial paralysis of the ordinary kind, if there be no progressive disease involving the nerve, it is usual for some recovery to take place, and it is not uncommon for the recovery to take place unequally, thus the upper part of the face may improve faster than the lower. In the lower the orbicularis oris improves fairly well, probably from being innervated from the opposite side.

If a case of simple facial paralysis receives no electrical treatment its rate of recovery will be slower than if it be assiduously treated, and the same is true of cases where the electrical treatment is too feebly carried out, and this is sometimes apparent when through the timidity or sensitiveness of the patients, very weak currents are employed, and the recovery is delayed. The cases of facial paralysis from ear or bone disease,

or from nuclear or other intra-cranial mischief are more unfavourable than those coming on from "cold." The hemiplegic cases usually recover fairly without treatment.

The electrical treatment should be in accordance with what has been laid down for paralysis in general, viz.: direct treatment of the seat of the lesion and of the affected nerve and muscles, and reflex stimulation of the skin of the face; treatment may be commenced at once. For reaching the seat of injury transverse applications to the skull (§ 145) are advised with the electrodes behind the ear or below it, the anode stabile on the affected side. Then the nerve and muscles may be treated with the kathode, each of the main branches of the nerves being stroked in a labile manner from centre to periphery, and each muscle being treated with the same pole stabile for half a minute, while the anode remains as at first. Lastly, the skin of the face may be gently treated with the induction coil and a moistened electrode.

196. **Paralysis of ocular muscles.**—Paralysis of these muscles may be treated by electricity. Occasionally from exposure to cold a paralysis of some of the ocular muscles is set up of a similar nature to the ordinary "rheumatic" facial paralysis.

Treatment is complicated by the difficulty of reaching the muscles. Their deep-seated position, the proximity of the retina, and the sensitiveness of the conjunctiva all help to make it practically impossible to excite contractions in them.

It has been proposed to use a fine electrode and introduce it into the conjunctival sac after that has been rendered insensitive by cocaine. Good results have sometimes followed a longitudinal treatment of the skull, the

kathode being placed stabile upon the closed eyelid. A current of 1 to 5 milliampères, and a duration of 30 to 60 seconds, are recommended by Erb. Dr. Buzzard* has recommended the use of the index finger covered by damp muslin as the active electrode (see § 143, hand electrode) or small sponges may be used. They are soft and readily adapt themselves to the surface of the eyelid. The reflex effect of applications to the skin of the face may also be tried, as recommended for the treatment of facial paralysis. Dr. Buzzard has reported two cases where permanent improvement did follow the constant current.

197. **Optic neuritis and atrophy.**—The battery current has also been used for optic atrophy and optic neuritis, several cases have been reported in which improvement of sight has followed. When atrophy comes on without previous optic neuritis, the prospects are considered less favourable. The treatment is (1) transverse currents through the temples with reversals; (2) longitudinal currents through the head, with the anode over the closed eyelids.

The prospects of improvement depend much upon the nature of the disease; when this is of a progressive kind, as in tabetic atrophy, good results can hardly be looked for. Capriati† recommends a trial, however, and considers that he has obtained improvement with a constant current of two milliampères applied longitudinally. His views have been summarised as follows: Electrical treatment is indicated in tabetic atrophy of the optic nerve, in cases in which the disease is not running a very rapid course, and before it has reached

* *Lancet*, 1875, ii., p. 485; *Brain*, 1890.

† *Riforma medica*, October 1893, Abstract in Weekly Epitome of *British Medical Journal*.

a very advanced stage. If employed in the early stages, it appears to do good, and arrests, with certain limitations, the morbid process, apparently by acting on the nerve fibres still unaffected. Better results may be anticipated from the application of the current antero-posteriorly, than transversely through the temples, although neither method has yielded results warranting great enthusiasm.

198. **Auditory nerve deafness.**—The treatment of nerve deafness by electricity sometimes gives good results. The method best suited is with the bifurcated electrode (fig. 64) and the battery current, using the negative pole, and interruptions. The current should not exceed ten milliampères. Even with this strength the patient must be watched for signs of faintness as syncope may even be produced. Short sittings of two to three minutes, with ten to twenty interruptions, are best. Under this treatment many patients will have the hearing improved, I have seen a remarkable increase of hearing power follow even the first applications, and the effect may be permanently good. The causes of nervous deafness of course are numerous, and the cases should be chosen; only those which from their history and the results of electrical testing appear to be favourable should be undertaken.

199. **Tinnitus aurium.**—Subjective noises in the ears can sometimes be dispelled by the battery current. From what has been already said in § 137 it appears that when the tinnitus is associated with an irritable state of the auditory nerve good results may be expected from the sedative action of the anode, which may be applied by a small electrode to the ear, or to the mastoid process just behind the ear, or to the skin immediately in front of the tragus. I have treated a

very large number of patients for this symptom, using as the active electrode (anode) the instrument figured on page 241, which is applied in front of the tragus or on the mastoid processes of both ears at once. The parts in contact with the skin should not be of less diameter than two centimetres. If the surface of the electrode is too small some soreness of the skin may be produced at the points of contact. A pad of moist absorbent wool should be placed between the electrode and the skin. The indifferent electrode is placed at the back of the neck, where it is kept in position by the pressure of the clothing; and a galvanometer and a rheostat (fig. 46) should be included in the circuit to enable the operator to introduce or remove a resistance of 10,000 ohms quite gradually. When everything is ready the current is slowly and steadily raised by the current collector to five milliampères (the rheostat being at zero) and allowed to pass for ten minutes. As the resistance of the skin diminishes the current will increase slowly, the galvanometer may be allowed to indicate eight or ten milliampères, each ear is then receiving half that current. If the current should be inclined to rise higher the rheostat must be brought into use to keep it at that strength. The patient should be instructed to pay attention to the noises and to give notice of any change occurring in them in the course of the sitting. The effect of the application of the anode to the ears is to diminish the noises, while that of the kathode is to increase them. The reverse sometimes happens, however, and therefore the patient must be tested to find out whether the current modifies the sounds. If it does so the prospects of improvement are good, and the patient should be encouraged to persevere. If neither anode nor kathode alter the sounds,

the prognosis is unfavourable, and it is hardly worth while to continue the treatment. In favourable cases the noises will diminish during the passage of the current; if the current be too quickly reduced at the end of the treatment the noises may return as loudly as before, but if it be reduced very slowly and gradually this does not happen. On this account the rheostat is an important part of the apparatus; at the end of the sitting the current is to be reduced by the rheostat first and afterwards by the collector. If it happens that the tinnitus is dispelled by the treatment, at first the relief is quite temporary and the noises will probably return within an hour, but after each sitting the period of quiet is longer until finally they disappear altogether. If the sittings are repeated daily for the first week much time will be gained, afterwards it will be sufficient to apply the treatment twice a week for a fortnight or three weeks, or a month, according to the progress of the case.

Tinnitus complicates nearly all the different forms of ear disease, for instance, it may depend upon the accumulation of wax, or it may be due to some other temporary disorder of the ear, which can easily be cured by proper local treatment, or it may occur in patients whose auditory apparatus is normal, as a part of some general morbid condition.

More commonly, however, some chronic ear mischief exists and the removal of the subjective noises may be a matter of great interest to the patient, even apart from his deafness or other troubles.

Electrical treatment is able to do a very great deal for some cases provided it be properly managed. If it is not done carefully the results will be unsatisfactory.

It has been objected to the electrical treatment that

it is difficult, and that the results are uncertain, and at the best only temporary, but when so little can be done in other ways for these patients it is at least a gain to be able to relieve by this method the very distressing symptom of tinnitus. Out of a very large number of patients who have been under our treatment for noises in the ears, about one-third have been freed by a course of treatment applied in the way already described. Some of them have certainly returned after the lapse of several months for further treatment, and in them the symptom has for the most part again yielded promptly to the renewal of treatment. Inasmuch as it is possible to determine at the first sitting whether the patient is likely to be relieved, one objection, viz., that of the uncertainty of the treatment no longer holds good, and it is but right and proper that the patient should be afforded the opportunity of a trial of electricity if the symptom of tinnitus be troublesome.

200. **Neuralgia.**—Severe nervous pains which might fairly be called neuralgic are often present in cases of injury or disease of nerves, but in many cases of neuralgia nothing so definite can be found. Fagge* recognises two distinct affections in what is commonly called neuralgia, he thinks that one is really due to peripheral irritation, but that it is not an irritation applied to the painful nerve, so that the patient is mistaken in his interpretation of the local sign. This is sometimes called reflex neuralgia, as an instance he cites the trigeminal neuralgia so often excited by disease of a tooth. In the other form of neuralgia, of which sciatica may be taken as an example, there is every reason to believe that the morbid process is going on in the trunk of the nerve which seems to be the seat of pain, and neuritis is therefore a better term than neuralgia.

* *Principles and Practice of Medicine.*

The electrical treatment of neuralgia may take either of two different directions. In the more rational one the action of the anode is brought to bear upon the seat of pain with the object of inducing a state of anelectrotonus, in the hope that its sedative effects may gradually leave a permanently soothing impression upon the nerve. In the other the principle of counter-irritation is followed, and by the production of painful cutaneous impressions it is sought to create a diversion, as it were, in the nature of the impulses conducted along the nerve, and so to remove the neuralgic condition. Counter-irritation is a very popular treatment for neuralgic pains, and electricity affords a counter-irritant of great convenience in application. Electrical counter-irritation has the great advantage that it does not damage or destroy the skin in the way that blisters or the cautery do. The electrical treatment of neuralgia is not to be followed blindly. In every case which offers itself a minute search should be made for any local cause or general morbid condition, and medical treatment must be brought to bear upon them when they are found. Electrical treatment is of especial value in cases where no exciting cause of the neuralgia can be discovered, or where it cannot be remedied by ordinary treatment. There are very many such cases, and electrical treatment often affords speedy relief. For the pains of tabes dorsalis, and of other general morbid conditions such as debility, anæmia, and hysteria, in which neuralgic symptoms are common and sometimes severe, electrical treatment may also be tried.

When painful points are present in a case of neuralgia, they are to be attacked by the stabile action of the anode. These painful points were described by Valleix, and shown to correspond to spots at which the cuta-

neous nerves emerge from bony canals or fasciæ, but perhaps they merely signify a general tenderness of the nerve-trunk, which is most manifested at those particular places where they are most subject to pressure.

The fifth nerve is one of the commonest seats of neuralgia, and in very many cases its condition is one of "reflex neuralgia," the teeth in particular being very commonly at fault, while errors of refraction should also be looked for. But not all cases of trigeminal neuralgia can be traced to an exciting cause, and the most severe form, known as *tic douloureux*, is often present when no source of irritation can be found. Duchenne's treatment for all forms of neuralgia (except those in which some gross lesion of the nerve was present) consisted in severe induction coil applications to the painful area, using a coil of many turns (§ 67), after drying and powdering the skin to diminish its power of conduction. If the skin were not first dried the current penetrating the tissues to the trunk of the nerve was likely to do harm instead of good.

He reports one or two cases of severe tic douloureux which derived great benefit from this mode of cutaneous counter-irritation, but confesses that his successes were rare.

In facial neuralgia statical treatment by the brush discharge (§ 101) will sometimes effect a cure. If the case is obstinate small sparks may be taken from the painful region. Daily applications should be resorted to, and in very acute attacks two or three applications may be made in one day. Tic douloureux will sometimes disappear as if by magic by simple positive charging.

The stabile action of the anode to the painful part is often of use in trigeminal neuralgia, and this is the

method which should be employed in the first instance. It is remarkable to see how a recent neuralgic pain will sometimes fade away quickly under this treatment. Old standing neuralgias are much less easily got rid of, but the same mode of treatment should be applied and persevered in.

The neuralgic pains which follow herpes are sometimes remedied very completely by electrical treatment. In a young married woman, who had had herpes of the area of the descending branches of the cervical plexus, a persistent neuralgic state of those nerves was left, it caused much suffering, and a good deal of anxiety because its nature was not understood. After it had lasted without improvement for nearly two years she came under electrical treatment, and was completely relieved within a fortnight. The localisation of the pain in the nerve-trunks and in their peripheral branches was clear in this case, and applications of the anode were used. There has been no return of the pain since.

201. **Sciatica.**—Sciatica varies much in severity, and in duration. It is now widely recognised that electrical treatment is useful for its relief, and a large number of cases are so treated. Although from time to time cases are met with whose sciatica persists for a long time in spite of treatment, yet as a rule they do very well. The constant current is the best method. General electrification with the bath, using the induction coil, or better still the alternate current from the mains, also answers well in many cases.

Steavenson[*] has published an account of sixty cases of sciatica treated by electrical applications; of this number thirty-seven were cured, eleven were improved, two

[*] *Lancet*, 1884, i., 105, 1886, ii., 113.

failed, and the remainder were uncertain. The method employed was to apply the kathode labile to the back of the thigh along the course of the sciatic nerve, and over the lower portion of the spine, while the anode was placed on the abdomen. The anode may also be placed on the lumbar spine. Each application lasted for eight to ten minutes, and the integument over which the electrode has passed becomes suffused with a bright blush, the patient experiencing a glowing feeling of warmth in the same tract. The stiffness of the muscles is also relieved, and the patient is able to bend down and get up from a sitting position with great ease for several hours, even after the early applications. In the electrical treatment of neuralgic pains large electrodes and large currents should be used. Prognosis is good if the first treatment produce even a temporary relief from the pain.

Counter irritation by means of the wire brush, using the long secondary coil, after drying the skin and powdering it with starch powder is sometimes efficacious in sciatica, and in other forms of neuralgia ; the battery current, however, is the better treatment of the two. Descending currents stabile, with a few interruptions (not reversals) to close the sitting are preferred by Remak, and most later authors.

Painful affections of other nerves, for example the anterior crural nerve, are sometimes met with, and may be treated in an analogous manner. Neuralgic pains in the nerves of the upper limb are not very common apart from definite signs of neuritis, although in women in middle life a painful numbness of both hands is not infrequent, and similar cases in men also occur. These respond well to treatment by the battery current. The effect of this upon the circulation of the part is always

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well marked, and the improvement probably depends in large part upon the vaso-motor effects produced.

Steavenson and others have described a neuralgic state of the pudic nerve.* The affection is associated with severe pains in the perineum, often periodic, and increased by walking; it is sometimes accompanied by a painful spasm of the urethra whenever an attempt is made to pass water. The pain sometimes extends beyond the perineum into the groin. The constant current applied locally will generally relieve the pain after a few applications.

202. **Anæsthesia.**—The treatment of anæsthesia is similar to that used for paralysis (§ 176). The cerebral anæsthesia which sometimes occurs with hemiplegia is usually not permanent, and it may very often be made to disappear by a few applications of the wire brush to the affected areas. Hysterical anæsthesia may also be dispelled in the same way as a rule, though not always.

When paralysis and anæsthesia coexist from disease of the spinal cord or spinal nerves, the prognosis and the treatment are similar for both. Very often the anæsthesia is much less marked than the paralysis, and it recovers more quickly in the favourable cases.

Anæsthesia of the sensory portions of the trigeminus has also been observed, see Erb, *Electro-therapeutics*, p. 572, and Althaus' case referred to on p. 285. Fagge quotes from Romberg a case which came on after exposure to cold and might therefore be of a similar nature to the cases of facial paralysis produced in the same way. Serious disease in the neighbourhood of the Gasserian ganglion may also produce anæsthesia of the face.

* *Lancet*, 1886, vol. ii., p. 181.

CHAPTER XII.

Other Conditions requiring Electrical Treatment.

Joint affections. Gout. Myalgia. The urinary organs. Nocturnal incontinence. Constipation. Sexual disorders. Diseases of women. Amenorrhœa. In parturition. Subinvolution. Cutaneous affections. Inflammatory exudations. Corneal opacities. Galactagogue effects. Ascites. Guinea worm. Suspended animation. Electricity as a test of death.

203. **Joint affections.**—The most important work upon the influence of electrical treatment in joint affections was done by Remak,* so long ago as 1856. As has been already observed, the special study of the uses of electricity for paralytic affections has tended to divert attention from many other of its important applications. Remak's cases are so well described as to leave no doubt that in his hands much benefit was afforded both in acute and chronic joint affections. He employed the continuous current exclusively, and, so far as one can judge, currents of fairly large magnitude. The cases which he has reported come under the headings of sprains and injuries of joints, and of chronic arthritis of rheumatic and other kinds.

Among the cases quoted at length by him the following is a striking one, though it is very like several of the others which are related, and it seems to be worthy of being reproduced in abstract.

A washer-woman, aged 36, fell from a table and felt her right foot to be twisted outwards; so much pain was produced that she could not walk. During the rest

* *Galvanotherapie.* R. Remak, 1860.

of the day and through the night she applied cold-water dressings, and the following day consulted Remak; she was obliged to drive to his house, and ascended the stairs with great pain and difficulty. The dorsum of the foot was much swelled and livid and very tender; the diagnosis made was laceration of some of the tarsal ligaments, and extravasation of blood. The aspect of the foot was such as to lead to the apprehension that gangrene might result. At the patient's urgent request treatment was applied. Owing to the thickness of the skin of the sole of her foot it was necessary to use fifty to sixty Daniell cells (equal to thirty-seven to forty Leclanché cells) in order to produce any sensation or reddening of the skin. By repeatedly changing the place of application of the electrodes he continued the application for twenty-five minutes. During this time the livid colouration disappeared, the œdema and the pain diminished considerably, and the patient could rest her heel upon the ground better than before. The warmth of the foot, increased by the current, continued until the evening, by which time a decided improvement was established, and she passed a good night without pain. Next day the colour of the foot was normal, and the symptoms were less severe; the treatment was repeated, on this and on the next three days. She was then so much better as to walk without lameness, and in a fortnight was practically well. The mode of application is not clearly stated but it appears probable that the positive pole was applied chiefly to the sole of the foot, but also to the dorsum, while the negative was on some indifferent part higher up the limb or on the trunk. The view taken by Remak in this and in similar cases which he reports is that the current produces a marked increase in the rate of circulation

through the part treated, by a general dilatation of its blood-vessels, and as a consequence of the improvement in the circulation the products of effusion are much more rapidly carried off than would otherwise be the case. This view is reasonable, and is perhaps the only one which is capable of explaining the rapidity of the cure.

The constant current may therefore be regarded as having a special power of improving the circulation in a part and as being useful in this way in promoting the removal of œdema and products of inflammation, and generally for the treatment of all injuries of joints.

With chronic pains of rheumatic origin the local application of the battery current, by means of large pads, proved equally useful in Remak's hands. He preferred stabile applications to labile, and the presence of the febrile state did not seem to him to be a contra-indication, but the best results were in patients who continued to have stiff and painful joints after the rheumatic fever had left them.

He quotes a case where there had been rheumatic fever; the patient was ill for seven weeks in his own house and for ten weeks in hospital. When discharged he was thin and pale, his joints were stiff, especially the knee and ankle joints, round which there was thickening. He was then treated by continuous currents applied to the several affected joints, and after six days of treatment was much more free from pain, had more power, and the thickenings had nearly disappeared.

Muscular spasm round an inflamed joint is also relieved by applications of the anode.

Among recent writers, Dr. Danion* has found applica-

* *Traitement des affections articulaires par l'électricité*, Paris, 1887.

tions of the coil current with the metallic brush to be a valuable treatment in the inflamed and tender joints of acute rheumatism; he reports that much relief to the pain and tenderness follows at once, strong currents are well borne, and the presence of fever is not a contra-indication to their use. Drosdoff† makes similar statements; he found that the sensitiveness to the induction coil was much lowered over the affected joints, and that treatment daily for five to ten minutes reduced the pain considerably, lowered the temperature of the joint, and shortened the course of the case. He employed moist electrodes in preference to the dry brush. This treatment might very well be tried in cases which do not respond satisfactorily to salicylates, and are showing signs of becoming chronic. It is probable that a rapidly acting vibration (§ 69) would be the best for these applications.

In a few cases of chronic joint affections which I have had the opportunity of treating relief has commonly been afforded, sometimes after a brief course of treatment. Chronic rheumatic pains of obscure nature will often yield in a most remarkable manner to electrical applications, even when they have proved most obstinate to other forms of treatment. The best methods of applying it are the electric bath, with alternating or interrupted current, or local applications of the anode.

204. **Gout.**—In gouty arthritis electrical treatment will hasten the recovery when the acute paroxysm is over. In the case of a hand or foot the part may be immersed in warm water to form a local bath, and the current caused to pass from the water to the limb. Ascending currents should be used. The addition of

† *Cent. f. d. Med. Wissensch.*, 1875, 17.

salts of lithium to the water has been proposed, and good results have been reported from it. Peterson* has proved that lithium can be introduced into a gouty part by this means with good effect.

205. **Myalgia.**—This is the name given to those pains which are felt in over-fatigued muscles; when patients are in a condition of debility, the amount of muscular exertion which sets up these myalgic pains may be so small that the connection between them and their true cause may be entirely overlooked. Hence myalgia is constantly confounded with hysterical, rheumatic, spinal, and others diseases.† The symptoms are pain in the muscles, made worse on movement, and tenderness. The skin over the muscles may also be very tender. The pains are often referred to one of the tendinous insertions of the affected muscle, and the trunk muscles are most commonly affected. Dr. Inman mentions as common seats of myalgic pains (1) the trapezius at its insertion into the occipital bone and into the spine of scapula; (2) the spines of the dorsal and lumbar vertebræ (origins of spinal muscles); (3) the front of the chest (origin of pectoralis major and minor) producing infra-mammary pain; (4) at the margins of the ribs, or at the pubes (insertions of recti abdominis).

Myalgia may exist in persons who are apparently healthy, and it may be difficult to decide what is the particular cause of the muscular fatigue which they suffer from; at the same time their pains may be very obstinate and very troublesome, and may resist all treatment until the diagnosis is clearly established, and rest for the affected muscles can be contrived. The movements which specially aggravate the pain must be

* Bigelow, *System of Electro-therapeutics.*

† Inman on *Myalgia*, Churchill, 1860.

carefully ascertained in order to decide upon the exact muscle which is at fault. General or local electrical applications may so improve the tone of the muscles as to enable them to perform without fatigue the work they are called upon to do. Local treatment acts usefully too by improving the circulation in the muscles. The battery current up to 20 milliampères may be used, the anode to the painful parts, the sitting may be terminated by a few reversals. This is the method advised by Erb. Induction coil applications to throw the muscles into contraction and exercise them are also useful.

206. **The urinary organs.**—Incontinence of urine is a symptom for which much can be done by electrical treatment. The cases of this complaint which are met with fall under two distinct groups. In one there is want of tone in the sphincter of the bladder, and urine is therefore expelled during any muscular effort which involves the action of the abdominal muscles, and in the other the muscular apparatus is normal, but the patients suffer from incontinence when asleep.

In women it is extremely common for there to be some inefficiency of the former kind, and in consequence a little urine is apt to be expelled from the bladder during muscular effort such as lifting a weight or during coughing, or sneezing, or even when they laugh heartily. If the weakness of the sphincter be rather more pronounced the incontinence becomes troublesome and annoying, and advice may be sought. The weakness of the sphincter may also be due to some dilatation or injury of the urethra, for example during parturition or after a digital examination of the bladder. The tone and power of the female urethra can be strengthened by electrical applications, and the patient's comfort may in this way be greatly increased. I have notes of a patient

who suffered from incontinence of this kind for which she was obliged in the daytime to wear an urinal apparatus, and she was always wet and uncomfortable. A course of electrical treatment completely cured her. In another case, equally successful, the incontinence was the result of an operation upon the urethra for the relief of some painful condition, possibly a caruncle. Since the operation the patient had been unable to hold her water, which escaped during any muscular exertion, so that her condition was most disagreeable to herself. After four or five weeks treatment she was quite well, and able to lift and carry her baby, a strong child a year and half old, without any leakage from the bladder. Other similar cases might be brought forward like the two already related. Even when the incontinence is part of a paraplegic condition, treatment applied to the bladder seems to be of service. I have notes of two women both of whom received injuries to the spine through jumping out of windows. They were referred to me for electrical treatment while they were recovering, and in both the power of the bladder seemed to be improved by treatment. At the same time they were and had been improving generally before coming under my care, and therefore the results of the electrical treatment they received are not so conclusive.

Another patient who had incontinence as the result of a long railway journey without any opportunity of passing urine was quickly restored to health by electrical treatment.

207. **Nocturnal incontinence.**—This affection has a totally different pathology to that of the kind of incontinence already discussed. In nocturnal incontinence the patients are quite able to pass or to retain their urine so long as they are awake, but when asleep

the bladder is apt to empty itself without awaking them. It is due to a persistence of the infantile condition of micturition. The education of a child includes the education of inhibitory centres which bring the reflex mechanisms of micturition under the influence of the will, so that the action of the bladder is continually controlled. If the control be imperfect the bladder may empty itself whenever the higher centres are in abeyance, as during sleep. A person suffering from nocturnal incontinence may pass water unconsciously in the daytime when asleep in a chair. As a rule one is told that the sleep is very sound in patients with enuresis nocturna, and Trousseau's amusing anecdote on the curability of this complaint by marriage proves the same thing.

The mode of action of electricity in enuresis nocturna is to stimulate the centres, both cerebral and spinal, by the repeated setting up of painful local impressions which tend in time to bring the inhibitory cerebral mechanism into more close relation with the reflex centres in the lumbar cord. It is important to try to combat the tendency to very deep sleep which exists in many of these patients. This may be attempted in various ways; for example, the number of the bedclothes should be reduced, so that the patients are a trifle chilly at night; and a clock which strikes the hours is also a useful thing to have in the bed-room, especially if the patient can be taught to awake when the clock strikes twelve, or any other hour which may be specified.

In children with enuresis nocturna it is important to search for any reflex irritation and to remove it when possible. Thus worms, oxaluria, or phimosis, if present, must be dealt with before resorting to electrical treatment.

The best mode of application for cases of the first group, when there is weakness of the sphincter muscle, is to introduce a bare metal sound into the urethra as one electrode, and to place the indifferent electrode upon the lower dorsal region of the back. The sound must not enter the bladder for more than a very short distance, otherwise but little current will pass to the walls of the urethra.

For nocturnal incontinence, applications to the perineum will often answer quite as well as the passage of a sound, and the latter may therefore be reserved for the more troublesome cases ; the use of a perineal electrode makes the operative procedure more simple and less formidable to the patient. Fig. 75 shows an elec-

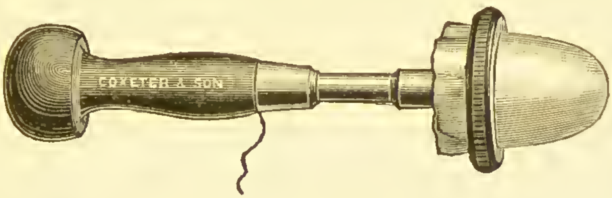


Fig. 75.—Electrode for enuresis.

trode of suitable shape. It consists of an acorn-shaped piece of metal fitted with a handle, and it is so contrived that the wash-leather cover can be changed in a moment for each application. The ring of vulcanite is pushed on over the piece of wash-leather and it holds it in place.

The electrode is to be placed upon the perineum in male children, and at the same place or between the labia in females. The currents used must be decidedly painful in order to produce a suitable impression upon the nerve centres. It is useless to undertake the electrical treatment of incontinence without direct applica-

tions to the perineal region. But where it is desired to avoid all manipulations of these parts, the difficulty can be surmounted by applications in the electric bath, using a pad pressed up between the thighs, outside the bathing dress, in place of the ordinary foot plate. The current then passes as desired into the perineal area. In the treatment of incontinence of either of the types described, the induction coil current applied strongly for eight minutes, and followed by a battery current of five to ten milliampères, with reversals every five seconds for three or four minutes, seem to give the best results. The constant current without reversals should not be used for fear of injuring the skin and mucous membrane. Soreness or ulceration may be produced by the constant current unless it be carefully watched.

In retention of urine occurring in hysterical subjects any painful local electrical treatment would probably prove effectual.

208. **Constipation.**—Peristalsis can be set up by electrical currents applied through the abdominal walls, and chronic constipation can be permanently relieved by its use. The poles may be placed one on the lumbar spine and the other on the surface of the abdomen, they should be of large size ; the abdominal electrode should be moved over the whole surface of the belly for a period of five or ten minutes. After a few applications the bowels become more regular. Dr. Wahltuch* reports seven cases in which the continuous current produced good results. His method was to use a large sponge for the positive pole, and an ordinary medium-sized one for the negative. The former was applied to the epigastrium, while the latter was slowly moved over the whole abdominal surface, "in the direction

* *British Medical Journal*, 1883, vol. ii., 623.

of the intestinal canal from the duodenum to the sigmoid flexure," where it was finally fixed, and the current of from five to thirty Leclanché cells allowed to pass steadily without interruption for ten, twenty, or thirty minutes. The operation was repeated every other day for periods of from three to six weeks. The bowels gradually became regular in their action, although all aperients and enemata were stopped, and they remained so after the cessation of the treatment.

Many other writers have reported similar results.

Another plan for obstinate cases, and for intestinal obstruction, is to introduce a bougie electrode (fig. 76)

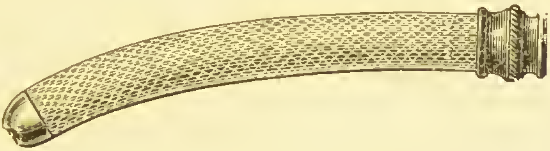


FIG. 76.—Rectal bougie electrode.

into the rectum, the other pole being kept on the abdomen as before; to avoid risk of setting up ulceration and soreness of the rectal mucous membrane, a combined douche and electrode has been devised by Boudet de Pâris, and in France a large number of cases have been treated for obstinate constipation by means of it, and with great success. It has even been used for cases described as intestinal obstruction. It is obvious, however, that the nature of the intestinal obstruction should be fairly well made out before undertaking to treat it by electricity.

An interesting article on this subject by Dr. Larat, of Paris, will be found in Bigelow's *International System of Electro-Therapeutics*.*

* F. A. Davis & Co., Philadelphia and London, 1894.

When there is constipation from want of tone in the muscular walls of the intestines, or of the abdominal muscles, with tendency to flatulent distension, a daily treatment by electricity does much good, and the diminution in the size of the abdomen is easily perceptible.

209. **Sexual disorders.** — Various morbid sexual conditions have been treated by electricity. The nervous supply of these organs is almost identical in position with that of the bladder and rectum, and the seat of application is somewhat similar in both cases.

Erb has advised that a small button-shaped electrode connected with the positive pole be held to the perineum, and another larger electrode (negative) be moved slowly up and down the lower dorsal and lumbar spine. The current may be from five to ten milliampères, according to the tolerance of the patient, and the time occupied may be ten minutes. Applications daily for a week, then every other day. In this way the symptoms may be dispelled. Local treatment by means of the wire brush has also been proposed for sexual debility. Electricity is in no way a sovereign remedy for this class of patient, and the restoration of lost sexual powers is generally a vain hope, except where the troubles are mental rather than physical. Even then medical treatment cannot do very much.

210. **Diseases of women.**—Electrical methods are largely made use of in gynæcological practice, not only for the sake of obtaining the direct effects (stimulating, sedative or trophic) of electricity, but also for electro lysis, and the galvano-cautery (see later Chapters). Much attention has been directed to the subject of the electrical treatment of fibro-myoma, and an immense amount of literature has been produced since the introduction of Dr. Apostoli's method of treating that

complaint by electrolysis of the uterine mucous membrane. His methods and results will be fully dealt with in the next chapter.

211. **Amenorrhœa.**—Electricity has been employed in the treatment of this condition since its first introduction into medicine more than a hundred years ago. Dr. Golding Bird had a very high opinion of the value of shocks from the Leyden jar for curing this symptom. His method was to transmit through the pelvis twelve shocks in succession from a small Leyden jar, the discharge being directed from the sacrum to the pubes. The induction coil current applied to the uterus has also been found efficacious by Panecki and others in patients with amenorrhœa from sluggishness of the uterine functions apart from chlorosis. The electric bath, by its effect upon nutrition, acts as an indirect emmenagogue in chlorosis, see § 159. When this condition is present general treatment is usually sufficient, and local applications are not called for, and indeed are undesirable. In healthy women in whom menstruation is regularly performed, electricity may certainly hasten the appearance of the flow, especially when it is applied to the abdomen or pelvic region. The electric bath may have the same effect.

It is best to suspend treatment in women during the menstrual periods, otherwise the flow may be rendered excessive, and in pregnancy it is better not to employ electricity at all for abdominal or bladder troubles.

Although electrical treatment in the healthy may produce or accelerate menstruation, it will not always do so when that function is in abeyance. The best results in this condition, as in others, are obtained by localising the treatment to the affected parts by the direct application of the electrode to the cervix uteri,

although in the unmarried it is usually sufficient to place one pole on the perineum and the other over the sacrum or the pubes, with the same precautions and in the same manner as advised for incontinence of urine. The induction coil current is the most useful; an electrode in the form of a bougie, insulated except at its extremity, is to be employed. Apostoli has advocated the use of a bipolar electrode for applications to the uterus, but it is not so satisfactory as the unipolar method, as the current tends to pass directly across from pole to pole at the extremity of the double electrode, without penetrating the surrounding tissues.

212. **In parturition.**—In a paper read by Dr. Kilner before the Obstetrical Society,* the use of the induction coil current is advocated during parturition. He found that uterine contractions could be excited or strengthened by its aid, though not in all cases. Sometimes the resulting contractions were very severe and prolonged, indicating possible risk to the child. The applications seemed to diminish the pains felt during the labour, and after the birth of the child ensured a firm uterine contraction, and much diminished the risk of post-partum hæmorrhage. Some medical men speak very highly of its value in childbirth, and make a practice of carrying a small induction coil in their obstetric bag. It has also been of service in flooding after miscarriage.

It follows that caution is necessary before applying electrical treatment to the abdomen or pelvic organs of a pregnant woman. Dr. Golding Bird,† speaks of having produced a miscarriage as the result of the Leyden jar shocks used by him.

* *British Medical Journal*, April, 1884.

† Golding Bird, *Electricity and Magnetism*, 1849, Lecture V., and Appendix B.

213. **Subinvolution.**—Dr. Grandin, quoted by Dr. Bigelow, recommends the treatment of this condition by the induction coil current. Its direct application to the enlarged and congested uterus, is said to produce contraction of the muscular fibres, improves the tone of the whole organ, diminishes the congestion, and leads to diminution in its size. The method seems to be rational, and is supported by Apostoli in a paper translated and published in the *British Medical Journal*, Jan. 14th, 1888, "On some New Applications of the Faradic Current in Gynæcology."

214. **Cutaneous affections.**—Electrical applications to chronic ulcers of the skin will improve their condition and promote healthy cicatrisation; a layer of moist lint or absorbent wool should be laid over the ulcerated part and the electrode applied to this, or the current may be caused to reach the skin through a locally applied bath. I have seen prompt and permanent healing follow treatment by the interrupted current of an obstinate varicose ulcer of long standing. Patients who are taking a course of electric baths usually lose any acne of the skin of the back from which they may have been suffering at the commencement.

Dr. Marquant,* has reported a series of twenty-three cases of eczema and eczematous ulceration treated by the electrostatic brush discharge with very good results. His method had previously been tried by Prof. Doumer, who has also published a communication in the same journal.†

The patients were placed on an insulating seat con nected to the negative pole of the machine, and the positive pole was connected to a pointed electrode and

* *Arch. d'électricité médicale*, 1894, pp. 329, 385.

† *Idem*, p. 141.

held close to the affected part. In his concluding remarks, he says, that the beneficial effect was superior to that obtained by any other kind of treatment. It was more quickly produced in those patients whose general health was good, than in those who were constitutionally unsound. The local pain, and the congestion and discolouration round the ulcers quickly disappeared, and healthy cicatrisation commenced rapidly.

Other observers have noted that obstinate pruritus can often be cured by the brush discharge; and it can also be relieved by other electrical applications.

These facts all show that the nutrition of the skin can be markedly influenced by electrical applications; and the warmth and redness which is produced by electrical treatment of a part is another sign of this direct effect upon the cutaneous circulation. It has long been known that chilblains respond favourably to electrical treatment.

215. **Inflammatory exudations.**—The continuous current by virtue of its vaso-motor effects, already referred to under the heading of joint affections, is sometimes of great use for promoting the resolution of chronic inflammations. In enlarged lymphatic glands, Remak and many other writers have mentioned this effect, or reported cases. I have at present under treatment a girl with numerous lymphatic glands of the neck which have very greatly decreased in size under treatment.

Scharff* (*Centralbl. f. Krankh. d. Harn und Sex. Organe*, I, 1894), claims to have employed electricity successfully in the treatment of cases of epididymitis. He does not wait until the affection had become chronic, but immediately and during the acute stage applies the

* *Brit. Med. Jour.*, (abstract).

anode to the lower part of the scrotum. The patient being in the dorsal position, a large electrode, with a maximum current of half a milliampère, is employed, the duration of the application being three minutes on the first occasion; this is afterwards increased to five and ten minutes, the increase being very gradual. The weak constant current thus employed should be carefully gauged with a sufficiently sensitive galvanometer, and the current closed insensibly with the aid of a rheostat. No unpleasant sensations should be thus produced, but the patient will subsequently on palpation be able to observe a considerable diminution or total disappearance of the tenderness which had previously existed. While in the same position a suitable suspender is applied, and the patient then allowed to walk about. Towards the seventh day the current can be increased to three milliampères, the same electrode, however, being still used for a few days, when it can be somewhat increased in size. The swelling at first reappears to some extent after each application, but usually diminishes gradually in three or four days. The cathode is placed above the groin and on the abdominal wall. By this treatment rest in bed can usually be dispensed with, the other advantages over the older methods being rapid and marked relief of the pain from the first, and greater rapidity in the disappearance of the swelling. Onimus also speaks very favourably of the good effect of electrical treatment in orchitis, and Dr. Picot, of Tours, has reported good results, in forty cases; they used currents of about five milliampères.

216. **Corneal opacities.**—Alleman* in a valuable paper on applications of electricity to ophthalmology,

* Bigelow; *System of Electro-therapeutics*, F. A. Davis and Co., Philadelphia and London.

gives an account of the treatment of corneal opacities by the continuous current. He says: "That from the observation of a number of cases, extending over a considerable time, he is convinced that the use of electricity promises the only treatment of avail in corneal opacities of long standing." The kathode is applied to the cocainised cornea, and has the form of a silver rod, seven milliampères in diameter, the flat end being used; from one half to four milliampères for one or two minutes are used. He has satisfied himself by strict tests that the results are really good. More care is needed with recent scars than with older ones.

217. **Galactagogue effects.**—Electrical stimulation applied to the mammary glands has been found useful for promoting the secretion of milk in nursing women.

Two patients who were suckling their infants were treated in this way in the Electrical Department at St. Bartholomew's Hospital, for failure in their milk producing powers. In one case a decided improvement followed. In the other the results were doubtful. Cases are also quoted by Drs. Beard and Rockwell. It is not often that the advice of medical men is sought for increasing of the mammary secretion.

218. **Ascites.**—Several writers have reported favourably of the treatment of ascites by application to the abdomen. The induction coil current should be applied energetically for fifteen or twenty minutes so as to set up vigorous and repeated contractions of the muscular walls of the abdomen. As a consequence the urine is increased and the ascites tends to disappear. The prospects of permanent cure of course depend upon the cause of the ascites in each particular case.

It is probable that battery currents might act even better than coil currents for the relief of this condition,

by their greater action upon the vascular system of the abdominal organs.

219. **Guinea worm.**—In the *British Medical Journal*, vol. ii., 1883, p. 1280, an account of the removal of a guinea worm with the aid of a battery was published by Mr. Alexander Faulkner.

One pole was held in the patient's hand, and the other was applied to the protruding extremity of the worm, the application was continued for an hour with gentle traction, and at the end of that time the whole had been extracted; the usual process of withdrawing the guinea worm little by little by traction for a few minutes daily is a very tedious affair, and may take weeks to complete it, even if the worm is not broken in the process. Mr. Faulkner's explanation of the action of the current is that the worm is benumbed and rendered incapable of resisting.

220. **Suspended animation.**—The aid of electricity is often invoked for the purpose of resuscitation when death appears to be imminent. It may be applied either in the form of brisk general cutaneous stimulation, in cases of narcotic poisoning, or with the special objects of stimulating respiratory movements, or of acting upon the beat of the heart.

In the first case the use of the induction coil, preferably with a long secondary wire and the metallic brush electrode, is advised. The region of the body which is stimulated is not of special importance; the applications may be made to any part which is exposed, and convenient of access.

A considerable reflex effect is produced by this cutaneous stimulation, and if the dry brush and the long wire coil are used there is much less risk of producing fatigue or exhaustion of the patient, than if a

short wire coil be used with moistened electrodes (§§ 67, 68). Stimulation of the face, especially of the nose and upper lip, tend to act favourably upon respiration. Duchenne has shown that stimulation of this kind applied to the precordia or to the skin of the back in the lower dorsal region, also influences the respirations. At the former situation inspiration is chiefly promoted, and in the latter expiration.

The phrenic nerves in the neck can be directly stimulated by the induction coil without difficulty, and contraction of the diaphragm will follow. No inconvenience seems to be produced by the proximity of the vagi. The method is as follows:—Two moistened electrodes of small size, about one inch in diameter, must be connected to the coil, one should have a key for making and breaking the circuit. These are to be applied under the posterior border of the sterno-mastoid muscles, which should be pushed forward, the key must then be closed and opened rhythmically about every two seconds, each closure causes an inspiration, expiration being allowed to take place during the intervals. This use of the induction coil to set up respiratory movements may be advantageously combined with mechanical artificial respiration by Silvester's method. Electrical stimulation of the phrenics in asphyxia, and in chloroform poisoning, has been successfully carried out. For further details Dr. F. W. Hewitt's book* may be referred to. Stimulation of the epigastric region may cause expiratory movements by acting upon the abdominal muscles.

Direct applications to the heart region do not readily affect the movements of that organ. If they do, the result is quite as likely to be harmful as useful. It is better therefore not to attempt it.

* *Anæsthetics and their Administration*, London, 1893.

221. **Electricity as a test of death.**—The electrical reactions of muscle have been proposed as a test of death. The contractility of living muscles persists for a few hours after death, and then disappears.

If the muscles of a person supposed to be dead cannot be caused to contract by a strong induction coil current, life may be considered extinct, if they do contract it is possible that he may be alive. Certainly no person should be buried if his muscles are still normally contractile.

Onimus and Legros* have shown that there is a stage in the death of a muscle at which it gives the reaction of degeneration (§ 130), that is to say, the irritability to the induction coil disappears first, while the response to direct battery current stimulation continues, giving rise to a *sluggish* contraction. This change sets in about four hours after death, and they relate a case in which the reaction enable them to specify correctly the time at which death had occurred.

* *Traité d'électricité médicale*, Paris, 1888.

CHAPTER XIII.

ELECTROLYSIS.

The laws of electrolysis. Actions in living tissues. Uses in surgery. Removal of hairs. Hairy moles. Warts. Nævus. Port wine mark. Aneurysm. Stricture of the urethra, of the œsophagus, of the rectum, of the Eustachian tube. Stenosis of the cervix uteri. Electrolysis in fibro-myoma. Dr. Apostoli's methods. Extra-uterine fœtation. Cancer.

222. **Electrolysis.**—The laws according to which substances are broken up by the passage of the electric current, and the terms used in considering the portion of a circuit in which electrolysis is occurring, were shortly given in §§ 39-41. According to the hypothesis of Grotthus the molecules are arranged under the directive action of current in lines between the anode and kathode, and all along this line a continual decomposition and recombination takes place, which, however, is only manifested at the poles under ordinary circumstances. It is perhaps better to look on an electrolyte with Clausius, as a body whose molecules are continually undergoing dissociation and recombination, even when no current is passing. When, however, an electric stress is set up, there is a directive force brought to bear upon the molecules that are in a free state, and a migration is set up, the electro-negative ions passing towards the anode, the electro-positive ones towards the kathode; if the electric stress is sufficient to overcome the tendency of the dissociated molecules to recombine, decomposition takes place.

Secondary reactions.—The view usually taken is that

the actual products of electrolysis are not given off at the electrodes; in general they react with a further portion of the electrolyte or of the solvent, or with the substance of the electrodes, and the products of this secondary reaction appear. Thus, for example, if a solution of sodium sulphate be submitted to electrolysis between platinum electrodes, the ions are sodium and the radical SO_4, but the former instantly decomposes the water present, and forms sodium hydroxide and an equivalent quantity of hydrogen, while the latter breaks up into SO_3, sulphur trioxide, which combines with water to form sulphuric acid, and oxygen, which is given off. The result is that the liquid about the anode becomes acid, while that at the kathode is alkaline. Of course, if the whole is allowed to mix, the two neutralise each other, and the only effect of the electrolysis is that some water has been decomposed.

If the electrodes consist of metals that are capable of being acted on by the ions action will take place, thus if copper sulphate is electrolysed between platinum electrodes the kathode will be found to be alloyed with the copper which will penetrate a considerable depth into the platinum (Gore). The anodes will be dissolved if the anion is capable of forming a salt with them, thus a copper anode is rapidly dissolved if used to electrolyse the salts of the mineral acids.

Curious secondary reactions may occur when mixed electrolytes are submitted to electrolysis. In general the most electro-negative ion of the mixture makes its appearance first, but it has been shown experimentally by Hittorf that all electrolytes present are concerned. If porous semipermeable partitions be placed between the electrodes, electrolysis will go on just as before, but by the help of such partitions it is possible to use a

series of electrolytes and to examine the reactions at the boundaries of each.

223. **Electrolysis of living tissues.**—The effects produced by the electric current in passing through the body appear chiefly at the points of contact, viz., the electrodes. These are local effects due to the chemical action of the substances set free by primary or secondary reactions in the electrolyte. These may be complicated by solution of the anode if it is made of a metal that forms a soluble chloride. Smaller effects may be looked for throughout the body, due to the chemical action between different electrolytes separated by cell walls or other semi-permeable septa, migration of the ions, or transference of the electrolytes due to electrical osmosis. It is easily seen, however, that these effects will be small with such currents as are used in treatment.

In a communication to the *Lancet*, December 1890, "The Electrolysis of Animal Tissues," Dr. G. N. Stewart gives a summary of his investigations. He found that "practically the whole of the conduction through animal tissue is electrolytic, and that the electrolytes are the inorganic constituents; when a tissue is electrolysed, almost the whole current passes by the salts; the changes produced in the proteids (coagulation, formation of acid and alkali albumen) must therefore be brought about by secondary electrolytic actions. Striking changes in the distribution of the salts were produced, changes sufficient, if produced within the body, to modify nutrition profoundly. The antiseptic action of the current was studied in the case of ordinary putrefactive organisms, and it was shown that it is chiefly, if not entirely, around the anode that this action takes place."

In the electrolysis of animal tissues there is a double

decomposition. The salts contained in the tissues split up, the alkalies are liberated at the kathode, and the acids at the anode. The alkaline metals, potassium and sodium, from their great affinity for oxygen, decompose the water in the neighbourhood of the kathode, liberating the hydrogen, which appears as bubbles of gas. The caustic potash or soda thus produced saponifies the animal tissues just as when applied in the ordinary way, and produces a soft deliquescent eschar, which is said to heal with less contraction than an eschar produced by either a wound, a burn, or an acid, and, therefore, is the most suitable to obtain when it is particularly necessary that the least possible contraction shall subsequently take place. The acids from the salts contained in the animal tissues are liberated at the anode; generally oxygen is liberated, but the reaction which takes place at the anode depends very much on its composition. If the electrode is made of zinc, chloride of zinc is formed, which exerts its own specific action on the tissues. By using anodes of iron or copper the local effects of salts of these metals can be produced. The eschar formed at the anode is said to be hard and comparatively dry.

The caustic effect of an electrode connected with the negative pole of a battery has advantages over the use of the ordinary caustic soda or potash. As pointed out by Dr. Poore, it can be applied to parts difficult of access, as the male urethra or uterine cervical canal. It can be applied to these regions and others, such as the larynx, pharynx, or nasal duct, where the application of other caustics is attended with danger or difficulty. Its effects are limited to the points touched by the electrode. The duration and extent of the caustic action is entirely under the control of the operator.

224. **Uses in surgery.**—Electrolysis is used in surgery as a means for producing destruction of tissue in a simple and minutely localised manner. This is effected indirectly by the action of the chemical bodies liberated at the poles during the passage of the current. As these bodies are different at the two poles, so the actions which take place at the poles differ from one another to a certain extent. The advantages of being able to localise the effects so precisely is well seen in the operation for the removal of hairs, for here the destructive effects are confined to such a minute area in the immediate neighbourhood of the hair follicle that no perceptible scar is produced although the hair follicle is eradicated. Electrolysis has been used for the following purposes:—(1). The removal of superfluous hairs, of moles and of warts. (2). Destruction of nævi, and removal of port wine marks. (3). Coagulation of blood in aneurysms. (4). Destruction of strictures in the urethra, lachrymal canals, œsophagus, rectum, and Eustachian tube. (5). Destruction of the fœtus in extra-uterine gestation. (6). Destruction of cancerous growths, and (7) for the relief of symptoms in fibro-myoma of the uterus. This last is brought about as a secondary process which has been found to follow electrolytic destruction of the uterine mucous membrane.

225. **The removal of hairs.**—If a fine needle connected to the negative pole of a battery of five or six cells be introduced into a hair follicle, electrolysis takes place round the needle when the circuit is closed, and the hair follicle is destroyed by the alkali produced; the hair can then be removed easily and does not grow again.

The method of operating is as follows:—The patient should recline in a good light. Having placed the in-

different electrode (anode) in contact with a convenient part of the patient's body, the kathode is attached to a fine needle set in a handle, the current collector is turned on to take up five cells into circuit, the operator then pinches up the skin round the hair with his left finger and thumb, and introduces the needle as closely as possible to the root of the hair, holding it in the proper direction for it to enter the follicle; the needle passes down readily to the required distance, a tenth of an inch, a current of about three milliampères passes, slight effervescence is seen at the orifice of the follicle, and at the end of five seconds or so the needle is withdrawn. As a rule the hair can then be easily lifted out by a forceps; if it still remains firm, the needle may be introduced a second time until it is loosened, though this is not a very good thing to do; it is rather better to leave the hair until another day; the current should be just strong enough to produce slight frothing. The best way to learn how to perform the manœuvre is by a few preliminary experiments on oneself. There is a certain amount of pain, but it is within the limit that can be borne without flinching, and an anæsthetic is not necessary. Cocaine may be applied to diminish the pain, either by utilising the process of electrical osmosis (§ 119), or by a preliminary application of the following ointment:—

℞	Cocaine hydrochlorat.	ʒ j.
	Menthol	
	Chloral hydrat.	āā ʒij.
	Lanoline	℥ss.
M. ft. ung.		

which is recommended by Dr. Hayes* as a local anæs-

* *Electricity in Facial Blemishes*, P. S. Hayes, M.D., Chicago 1889.

thetic application. It is not of very much use. Sometimes it is advised that the hair be grasped by an epilation forceps held in the left hand while the needle electrode is being introduced, and the electrolysis is allowed to go on until the hair comes out, but the method first described is much the best. It is best to use for the needle a very fine platinum wire, blunt pointed, because such a needle is less likely to penetrate too easily and so pass away from the hair follicle. It can be sterilised before use by heating to redness, and is better than a steel needle. The current must be closed before the needle has been placed in position. A key in the handle is therefore unnecessary and troublesome.

FIG. 77.—Needle electrode for epilation.

A good deal of practice is required to perform this little operation skilfully, no force must be used in removing a hair, if force is used the hair will come out before the follicle is destroyed, leaving its root behind, and a new hair will grow up from it. When many hairs are to be removed they should be done at successive sittings. Patients as a rule become restless from the pain of the operation after a time, and as soon as signs of this begin to appear, it is best to suspend the operation. It is possible, however, with a good patient, to remove fifty hairs at a sitting. A tiny eschar with

a small zone of redness is left round the follicle. Several hairs in close proximity should not be attacked at one time, for fear less the nutrition of the skin should be so much interfered with as to lead to a small ulcer and consequent scar, but the hairs should be removed sporadically, until at the last few sittings the few remaining ones can be gleaned off and the place left smooth and bare. If the patch of hairs is small the sittings must be less frequent, once a week being quite often enough. When there is plenty of room to attack a fresh part each time the sittings may be repeated more often, care being always taken not to injure the skin at any one point too much.

It is as well to caution patients that there will be a certain percentage of returning hairs, but that these can be dealt with a second time if any should so return.

It is very easy to overdo the treatment and leave scars. It is not wise to attempt the removal of a fine downy growth on the upper lip of young women.

226. **Trichiasis.**—The removal of eyelashes for trichiasis is satisfactorily accomplished by electrolysis, and is by far the best method of treatment for this condition. I have had under treatment a man of middle age suffering from this complaint. At the commencement of the treatment both his corneæ were hazy from the presence of pannus, the result of the continued irritation by the turned in eyelashes; the removal of the eyelashes was persevered with until every one had been removed; by that time the corneæ had recovered perfect transparency. The patient has continued free from trouble from his eyelashes since.

227. **Hairy moles.**—The best treatment for small hairy moles is epilation; when the hairs have been removed very little will be seen of the mole, for a good

deal of the pigmentation of the skin between the hairs will disappear when they have been taken out, but if it should be much pigmented, the electrodes suggested by Mr. R. W. Parker and figured by Dr. Steavenson,* can be used to produce superficial destruction of its surface. These electrodes (fig. 78) consist of flattened metal

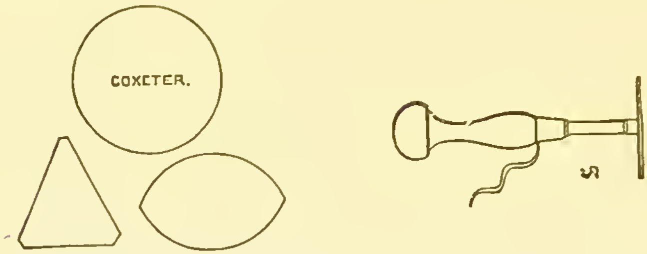


FIG. 78.—Plate electrodes.

plates covered with platinum foil, of various shapes and sizes, and with handles, they are attached to the negative pole of the battery and held to the moistened surface of the mole, whilst a current of twenty or thirty milliampères is passed through them; electrolysis is set up, and a slippery and alkaline material is produced, and the surface is gradually destroyed. The plates are inclined to slip during the operation, this must be guarded against, or sound skin may be destroyed as well as the mole. A small plate kept moving gives better results than a large one held stationary. Chloroform must be given as the process is very painful. If epilation has not first been carried out, this process must be continued until the skin is destroyed down to the depth of the roots of the hairs, which can then be wiped away, but a scar follows this operation, and may be almost as disfiguring a blemish as the mole had been.

* *Electrolysis in Surgery*, Churchill, 1890.

Therefore epilation should first be performed, and then the plates may be cautiously used if necessary, for sometimes a slight superficial treatment will remove pigmentation without destroying the whole depth of the cuticle. These plates are unsatisfactory for they do not destroy the skin in a smooth and level manner; much of the current passes from them through the skin by certain points of least resistance, and the result is to produce an unevenly destroyed surface.

Warts may be destroyed by electrolysis by transfixion with the negative needle, but the process is rather painful unless the wart is quite small.

228. **Nævus.**—Electrolysis is a very convenient way of destroying nævi, and in some respects it is superior to all the other methods, but, to secure first rate results, a certain amount of practice is necessary, and several sittings are required except for the very small ones. The chief art in treating a nævus lies in the careful regulation of the current used and in knowing when to stop. It is easy to electrolyse a nævus in such a way as to destroy it and cause it to slough away completely, but this leaves a large scar, and results of the same kind can be obtained by ligature or caustics. The object to be aimed at in the electrolysis of nævi is to carry the destructive action just so far as to coagulate the blood and break up the blood-vessels without producing a general necrosis and sloughing of the whole. When the nævus is entirely subcutaneous, it is most important to save the skin, for then the nævus is destroyed without any scar except at the minute points where the needles were introduced. When the nævoid tissue is quite superficial and very florid and involves the actual thickness of the skin, it is difficult or impossible to destroy it without some sloughing.

The usual plan of treatment is as follows:—Needles attached to one or both poles of a battery are introduced into the nævus, a galvanometer being included in the circuit; the current is then very gradually raised from zero up to 20, 30 or 40 milliampères. If both poles are used care must be taken that needles of opposite poles do not touch one another, for if they remain in contact the current simply runs to waste through the metallic circuit so produced, and the nævus tissue is unaffected; if they come into momentary contacts, the patient receives a shock each time they touch and separate. Soon after the commencement of the operation the tissues round the needles begin to change colour; round the positive needles there is hardening and pallor, and round the negative needles frothing is produced with the evolution of hydrogen gas. The positive needles become firmly adherent to the tissues in which they are imbedded, and force is required to withdraw them, on this account bleeding is more likely to occur with the positive than with the negative needles. The negative needles become very loose and are apt to slip out, but they must not be allowed to do so, for the current must not be suddenly interrupted for reasons already mentioned. If the tissues round the needles become livid or blackened sloughing of the part will follow. This change shows itself first at the negative pole. The position of the needles must be changed before this by taking them out and re-inserting them one at a time in other parts of the nævus, until the whole of it has been treated.

The nævus becomes swollen and harder during the process of electrolysis and the skin round it becomes reddened. From five to ten minutes is a suitable length of time to continue the electrolysis, but this should be varied with the size of the nævus. If the

nævus is very extensive it must be dealt with in detail, part being attacked at each sitting until the whole has been destroyed.

The needles are to be carefully withdrawn after the current has been very gradually lowered to zero, they must on no account be plucked out while the current is still running. The negative needles are easily withdrawn, but the positive may be adherent and should be twisted out gently. A little bleeding may follow from one or two of the punctures, but it is rarely of any importance. The after-treatment is simple. Collodion containing iodoform, one drachm to the ounce, is to be painted over the nævus; this can be left for four or five days, it should then be removed, and the place treated with boracic ointment. If any suppuration or local sloughing should develop, a poultice at night, with some zinc lotion by day, will be a suitable treatment. Many of the smaller nævi dry up and need no second application. It is impossible to avoid destruction of the skin and scarring when the nævus is cutaneous, but the scars produced are much smaller than might be expected, and are perhaps less extensive than after other surgical methods of treatment. When seen a year afterwards they show remarkably little. Sometimes only one set of needles, usually the negative, is introduced into the nævus, the circuit being completed through the patient's body by using a large pad for an indifferent electrode. In this case the resistance is higher, and a larger number of cells is required. There is a greater risk of shock or faintness, especially with nævi of the head and face, but with ordinary care the operation can be carried out successfully. The advantages of this method are that there is no risk of short circuiting and shocks from contacts of needles of opposite pole in the nævus itself, the

density of the current is more uniform, and therefore the destructive process is also more uniform. In fact this method is the one which I adopt in most of my cases.

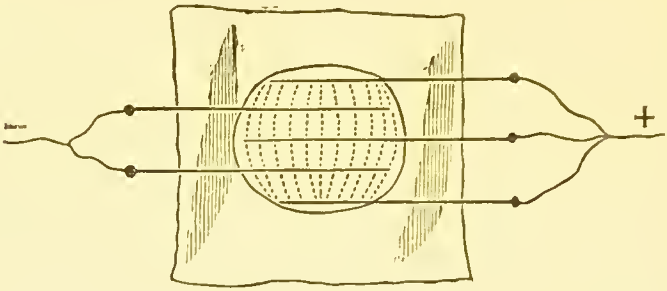


FIG. 79.—Electrolysis of nævus. Proper position of needles.

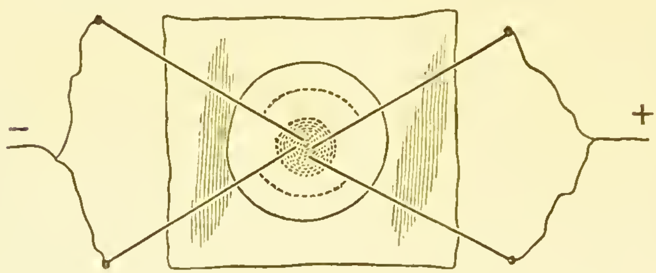


FIG. 80.—Electrolysis of nævus. Improper position of needles.

Great care must be taken that the pad electrode and its conducting wire are well covered and that no bare metal touches the skin anywhere, the slightest oversight in this matter may lead to electrolysis where it is not wanted, namely, at the seat of the indifferent electrode.

The rate of destruction depends upon the density (§§ 38, 106) of current in the part; if needles of both poles are introduced irregularly, it is very likely that the current may be concentrated round the points where

they are nearest together, and be very feeble in the more remote parts. The diagrams (figs. 79 and 80) represent the conditions under two different arrangements of needles, in the first the needles are placed in such a way as to be equidistant, and the density of current is therefore uniformly diffused. In the second, they are all very near together at the points and there the current is of far greater density than at the periphery of the nævus, the effect of such an arrangement would be to produce a slough at the centre, while the periphery would not be destroyed at all. In order to simplify the introduction of the needles in a proper manner, the

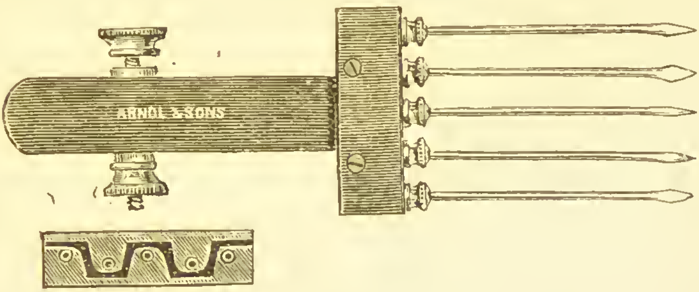


Fig. 81.—Bipolar fork electrode.

writer* has devised an instrument (fig. 81) consisting of a handle to carry the needles; two, three, four or five can be screwed into it, and they are so arranged as to be alternately positive and negative (see the smaller of the two figures). By this means the needles are kept at equal distances from one another throughout the operation, and they cannot touch accidentally, and they can be moved about simultaneously inside the nævus so as to bring the whole of it under the action of the current.

* Dr. Lewis Jones, *Brit. Med. Journal*, Feb. 20th, 1892. "An improved instrument for the electrolysis of nævi."

It is difficult to formulate a rule for the current to be used, but it is the density of current which is the important point, more so than the actual number of milliampères employed. The current density should not exceed twenty milliampères per inch of positive needle if it is desired to avoid sloughing in a nævus. Thus, with four needles introduced for a distance of one inch, two being positive, a current of forty milliampères would be amply sufficient, and with twice the number introduced for half that distance the same current would yield the same effects.

The cells of an ordinary portable battery will do very well for the electrolysis of nævi, but as the current required tends to exhaust small cells rather fast, it is better to use larger ones when portability is not essential. The galvanometer must read up to fifty milliampères. From twelve to twenty cells are sufficient.

The usual arrangement of wires for the attachment of the needles is shown in the figures, it consists of two parts, (1) a main lead (fig. 82) from the pole of the battery, terminating in a binding screw, and (2) several secondary leads or branches each carrying a needle, and all attached to the binding screw of the main lead. The needles should be of platinum, and insulated except at the ends, in some the metal may be bare for a distance of half an inch, and in others for an inch, to suit the different sizes of nævus. The insulation of the needles is not very important, and it is difficult to obtain an insulating coat which does not greatly increase the thickness of the needles and act as an obstacle to its introduction. Hard varnish, applied each time, is the best. The whole of the bare part of the needle must be buried in the nævus, in order that an insulated part may be in contact with the skin,

this diminishes the size of the marks which will be left at the points of entry, and it is for this reason that

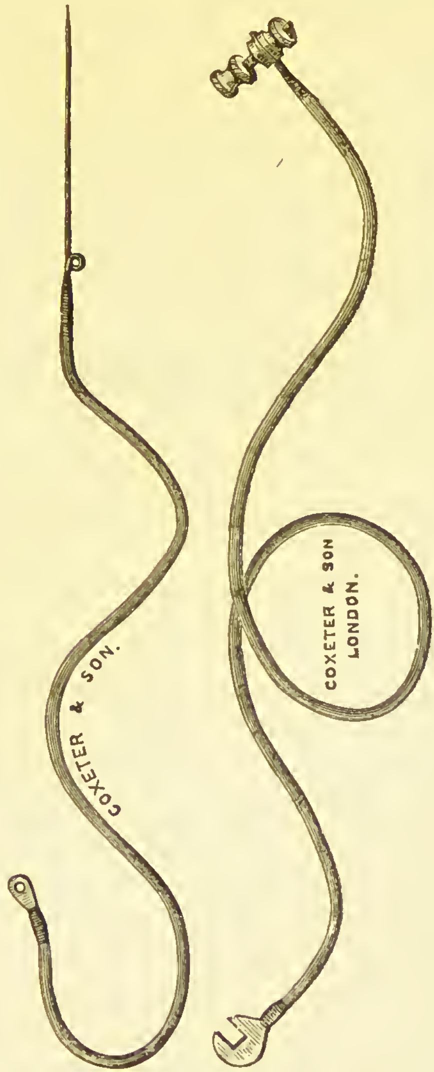


FIG. 82.—Attachment of needles for electrolysis of nævus.

needles are required with bare points of varying length. When needles of one pole only are used, the other

(indifferent) electrode must be a pad of good size, to diminish as much as possible the density of current at its surface of contact, and also to diminish the resistance.

Care must be taken to prevent the spare needles from touching the patient's skin by accident, or they will corrode it at the point of contact.

The needles are attached to the ends of the wires in various ways. Soldering is much the best. The clamp (fig. 83) or unions effected by twisting the wire round the needle are bad, for they are apt to break adrift at a

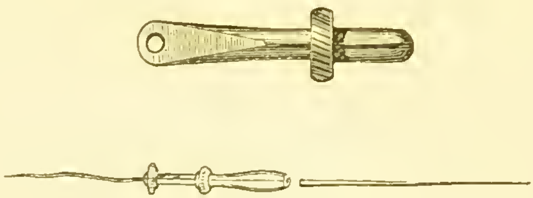


Fig. 83.—Clamp needle holder.

critical moment and give rise to shock. With large currents such shocks are undesirable in the case of infants under chloroform.

An anæsthetic should always be given when possible, as the pain is severe during the passage of the current, though it does not persist after the operation is over.

The needles may be introduced either in a direction parallel to the surface or vertically; the former is the best when the nævus has any appreciable thickness.

In some superficial nævi a multiple puncturing with a vertical needle gives the best results, sufficient skin survives between the punctures to preserve the mark from being truly cicatricial.

The electrolytic treatment of nævus is not so simple

a matter as it may appear to be at first sight. Those nævi which can be easily excised should not be attempted by electrolysis, which should be reserved for those which are difficult to do by other methods. If the nævus is very small, that is to say, under a fifth of an inch in diameter, it may be completely destroyed in one sitting, and the resulting scar will not be of any great moment; and here I would urge very seriously the importance of dealing with nævus at the first possible opportunity after birth. Nævi which are quite small at birth are often allowed to grow enormously before any interference is thought necessary, with the result of deplorable disfigurement, which might have been completely prevented by timely treatment. They should always be attacked at once.

It is true that nævi may spontaneously disappear, but this is a rare occurrence, and the usual tendency of a nævus in the young baby is to grow rapidly. Indeed, after electrolysis, a nævus will often commence to grow afresh, although at the time of operating it seemed to have been completely destroyed. I have known such re-appearance to take place after a nævus had been perfectly healed for over two months. The same thing happens even more commonly when a nævus is treated by cautery or caustics, the action of both being superficial, and the nævus growing afresh underneath the scar. The margin of a nævus is especially prone to start fresh growth, and must be treated as thoroughly as possible.

Nævus is commoner in females than in males, and it is found on the head and neck more often than upon the trunk or limbs. Out of 173 consecutive cases in the Electrical Department of St. Bartholomew's, 121 were in female, and 52 in male children; in about three

fifths of these the nævus was situated on some part of the head or neck. I have once seen a nævus of the ocular conjunctiva. At the anterior fontanelle it is not uncommonly met with, and can safely be treated by electrolysis ; the needles of course must not be pushed through the meninges.

229. **Metallic electrolysis.**—Of late the use of copper needles has been advocated under this title, the idea being to deposit a salt of copper in the nævus or other tissue under treatment. More marked effects can be produced by copper than by platinum needles, and the metal does not appear to leave any permanent stain. The positive pole must be used. Ordinary platinum needles can be coated with copper electrolytically in a bath of sulphate of copper, using a piece of copper sheet for the anode and making the needles to be coated the kathode of a battery of one or two Leclanché or other cells ; the process only takes a few minutes, and the needles can then be taken out, washed and used for electrolysing a nævus. The effect visible is rather different to that of electrolysis with the negative pole and platinum needles, and therefore a certain amount of practice is required before one becomes an adept with the coppered needles ; but good results can be had, and especially when a more thorough destruction of a part is desired. The tissues round the needle turn of a dull greenish colour. The negative pole must be used in the form of a pad electrode, as the deposition of copper from the needles takes place only at the positive pole.

230. **Port wine mark.**—This form of nævus can be attacked by a tattooing process, using a fine needle, and inserting it vertically into the skin, the current used must be under five milliampères, and the appli-

cation quite brief There is no need to use several needles at once. The operation should produce minute points of destruction without confluence of the resulting minute scars. The negative pole is best. If a port wine mark be closely scrutinised, the position of many of the capillaries can be seen, and these are the points into which the needle must be especially directed. The area affected must be treated in a sporadic manner as advised for the removal of superfluous hair. The result is a distinct improvement in the aspect of the surface; the treatment must be carried out slowly.

231. **Aneurysms.**—Electrolysis has been tried for the cure of aneurysms, particularly for those which are not suitable for treatment by ligature or compression. In many of the cases recorded, some temporary increase of hardness has followed the operation, but the cures are but few, and the punctures made in the sac walls have sometimes led to hæmorrhage. The piercing of the wall of the aneurysm by the needles, with the consequent risk of bleeding is the chief defect of the operation; it may be lessened by the use of needles insulated except near their point, so as to limit the electrolytic process to the interior of the aneurysm, and to prevent any action upon its wall.

The method which is generally preferred is to introduce both positive and negative needles into the tumour; the needles attached to the positive pole become corroded if they are made of steel, but this is not an objection, for coagulation is promoted by the salts of iron so produced. Ciniselli* has collected twenty-three cases, of these, six recovered, sixteen died, and one case disappeared from observation. Some of those reported as cured had re-

* *Treatment of Thoracic Aneurysms by Electro-puncture*, Milan, 1870.

lapses a few months later. See also *Brit. Med. Journal*, 1890, vol. i., p. 1276, for a report of successful results after thirteen sittings in a case of aortic aneurysm.

As far as can be made out from the details furnished, the electrolysis of aneurysm requires large currents and long sittings. Twenty, thirty, or forty cells have been used, and the application continued for half-an-hour or more. Assuming the internal resistance to have been 100 ohms (it may have been much lower), and putting the electromotive force of the cells used at one volt a piece, then twenty cells would give a current of about 200 milliampères, and forty would give twice as much. This current if continued for half-an-hour, would be sufficient to set free a considerable amount of electrolytic gases, and in some of the cases we read that the tumours became resonant to percussion after the operation. The free acids and alkalies produced by the electrolytic separation of the neutral salts of the blood would probably soon recombine in their passage along the blood stream. The clotting set up in the aneurysm is soft and diffluent.

232. **Stricture of the urethra.**—Modern writers on this subject refer to Crussel, 1839, as the first to use electrolysis for the cure of this condition, and to Mallez and Tripier* as the first to practise it systematically. A good deal has been made of the difference between electrolysis of a stricture, and destruction of it by the caustic alkali set free electrolytically at its surface, as though the former process were something essentially different and less injurious than the latter. It has also been claimed that the stricture can be cured without any destructive action upon the mucous membrane which

* *De la guerison durable des rétrécissements de l'urethre par la galvano-caustique chimique*, Paris, 1867.

covers it. I am disposed to think that the yielding of a stricture during electrolysis is mainly due to its actual corrosion by the alkali liberated at the negative pole, and that the mucous membrane, because it is nearest to the electrode, must be the first part to perish. It is possible that the current produces some relaxation of the tissues of the stricture, perhaps by a vaso dilator action.

Mr. Bruce Clark in a paper on the subject* says:—"Where I have had an opportunity of treating an orifice stricture it is clearly demonstrated that with such currents as one usually employs, no solution of epithelial continuity takes place," and again:—"That absorption does take place can be witnessed when a stricture at or within half an inch of the urethral orifice is submitted to treatment. In these cases the surface of the epithelium is seen to be gradually converted into a glutinous saponaceous-looking material. If this be wiped carefully away, the surface is seen to be red and somewhat congested in appearance, but it is perfectly evident that the epithelium is not entirely removed with such currents as I am in the habit of employing."

In a paper read at the Annual Meeting of the British Medical Association, in 1886, by Dr. W. E. Steavenson, the following account of electrolysis of stricture occurs:—"No doubt this procedure will become one of the recognised modes of treatment of stricture in this country, as it has been on the continent and in America. It may not be destined to become the most usual mode of treatment, because of the apparatus required, the numerous details connected with its application, and the great care and patience required for its successful employment.

* "The Treatment of Stricture of the Urethra by Electrolysis," *The Practitioner*, 1886.

"For the treatment of stricture of the urethra, the electrodes we have used are catheter-shaped gum-elastic bougies, ending in a metal nickel-plated piece connected by a copper wire, with a binding screw on the handle. The indifferent electrode is placed upon the patient's back if he is in the recumbent position, or it may be placed on any other convenient part of the body. The metal plate is made positive.

"An ordinary bougie is first passed down to the stricture, and by its means the distance of the stricture from the meatus is ascertained, and a mark made on the bougie. It is then found out what sized bougie will pass the stricture. Say, for instance, it is ascertained that a No. 3 bougie (English) will pass; a No. 5 electrode is then taken and passed down to the stricture, where it is arrested. It can be made certain that the electrode is arrested at the stricture by previously marking it, after measurement and comparison with the bougie first passed. When the electrode is in position against the stricture, it is connected with the negative pole of the battery, the circuit is closed and the current gradually increased without breaks until the maximum strength is reached that it is intended to employ, namely, about five or six milliampères. The electrode is kept gently pressed against the stricture in the direction of the ordinary course of the urethra. No force is used, but the current is allowed to do the work. The surgeon has to keep his attention continually applied to the electrode, so as to guide it in the right direction, otherwise a false passage may be dissolved into the side of the urethra. Therefore skill in passing a catheter is a requisition. In the hands of a surgeon who knows his way into the bladder, a false passage is not more likely to be produced than is the case in pass-

ing an ordinary catheter. The electrode is to be kept gently pressed against the stricture in the normal direction of the urethra until, from the dissolution of the obstacle in front of it, it passes into the bladder. The current then should immediately be cut off, and the bougie withdrawn. The duration of the operation depends upon the density of the stricture and the strength of the current used.

"Although as a guide I have mentioned that the current should be about six milliampères, the strength really used is regulated by the patient himself. One great object is to avoid giving pain, and by this means a too great destruction of tissue is prevented. We require our patient to be conscious; therefore no anæsthetic is used, or indeed necessary, for the only sensation produced is a slight pricking at the seat of the stricture. If anything amounting to pain should be complained of, the strength of the current has to be diminished. On removing the electrode, there is sometimes found on it some slimy matter like disintegrated tissue; and the patient is often immediately after its withdrawal enabled to pass urine with increased facility and with very little discomfort. After the operation we have left the patient entirely free, without any interference, for usually the space of ten days or a fortnight, and then have tried what sized bougie would pass. If no disintegrated tissue comes out upon the electrode, some sort of slough or eschar is thrown off at a later period—the next day, or a day or two after the operation, during the passage of urine.

"Going back to the example we have already taken, if, after dissolving the stricture, it has been possible to pass a No. 5 electrode into the bladder, after the rest of a fortnight it is usually found that a No. 7 bougie

can be passed. Should that be the limit of the increased calibre of the passage, a No. 9 electrode is taken, and the same operation repeated as before described, and so on after the interval of another fortnight, until the stricture is cured. The results of our investigations may be summed up as follows:—In the treatment of stricture of the urethra by electrolysis, there is usually no bleeding. If hæmorrhage does occur, it is accidental, and usually shows that a too strong current or the wrong pole of the battery has been used. No anæsthetic is required. It is an assistance to the operation that the patient should remain conscious. The pain or discomfort produced is trifling. The patient can in the case of a slight stricture pursue his ordinary occupation during the period of treatment. In the majority of cases there is no contraction or return of the stricture.

"Eschars formed by caustic alkalies are said to heal with less contraction than wounds produced in any other way, and electrolysis with the negative pole is a means of applying the destructive action caused by the caustic alkalies to parts difficult of access, and in a way which is impossible by any other method. But beyond this, the current appears to set up an absorptive action around and within the dense cicatricial tissue which forms the stricture, so that it gradually disappears. This we have seen in several ways. After electrolysis has proceeded so that the electrode will pass into the bladder, it is found a fortnight later that a bougie of two sizes larger can be passed. Additional absorption must therefore have taken place in the interval. And again in penile strictures, where we have been able to feel the hard dense tissue of which they are formed, a few days after electrolysis, we have noticed that this hardness has disappeared.

"This progressive improvement after the termination of treatment is very remarkable, and lends some colour to the belief that an actual absorption of fibrous tissue may be determined by the passage of the current. It has also been stated that the cure is more permanent than it is after ordinary dilatation."—For reports of Mr. Bruce Clarke's cases, with their subsequent history, see *Practitioner*, 1886, and *British Medical Journal*, 1890, vol. i., p. 942.

In a letter of recent date (1892) Mr. Bruce Clarke writes that he still considers the results of electrolysis to be extremely good and permanent in cases of stricture. Of a patient who was treated by him in 1885, he says:—"I saw him a few days ago, and passed a No. 11 with the greatest ease. No instrument has been passed since the operation, except by myself once or twice for purposes of diagnosis."

233. **Other strictures.**—Electrolysis has been recommended for stricture of the œsophagus by most writers on medical electricity. Stricture of the rectum can also be treated by means of electrodes shaped like rectal bougies, which are connected to the negative pole of the battery. A bougie is selected of a size rather larger than the stricture, to which it is applied firmly. A current of five or ten milliampères is passed. After a variable time the stricture gives way, and the bougie passes through it. The time of each operation may be from ten minutes to half an hour. The operation is repeated with a larger instrument in ten days or a fortnight. No anæsthetic is required.

234. **Eustachian obstruction.**—In the *Lancet* for Nov., 1888, a paper on electrolysis of the Eustachian tube was published by Mr. Cumberbatch and Dr. W. E. Steavenson. The authors described their methods as

follows:—"The instrument consists of a vulcanite Eustachian catheter and an electrical bougie (fig. 84), the bougie is made of a fine flexible copper cord about seven or eight inches long, insulated by vulcanite to within an eighth of an inch of its end. The ends are soldered into a nickel plated cap. The bougie is small enough to pass along the catheter, and exceeds it in length by about an inch. The handle end of the bougie is provided with a binding screw, to which the insulated copper wires are also attached, for the purpose of connecting a rheophore from the battery. On this end of the bougie an inch is marked off divided into eighths.

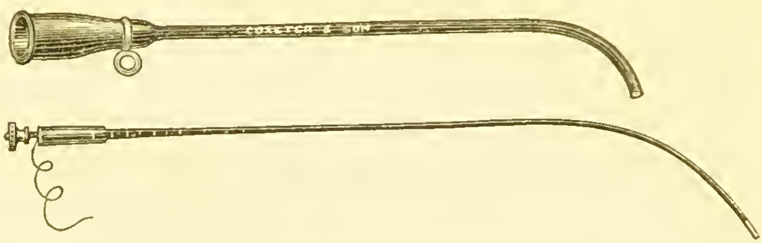


FIG. 84.—Eustachian catheter electrode.

Each eighth of the inch passes into the catheter as one eighth protrudes at the other end. It is therefore possible to tell, when the catheter is in the orifice of the Eustachian tube, how much of the bougie is in the canal. On the catheter there is a metal ring, or some other mark, to indicate the direction of its end when it is being inserted.

"Electrolysis of the Eustachian tube is performed in much the same way as the electrolysis of the other mucous passages. A pad connected with the positive pole of a battery is moistened and placed at the back of the patient's neck. The Eustachian catheter is then passed along the nostril and guided into the tube; the

bougie, already attached to the negative pole of the battery, is passed along the catheter and Eustachian canal as far as it will go, until it meets an obstruction. The circuit is then closed. A galvanometer should be included in the circuit, and the current gradually increased up to four milliampères. A frizzling noise will be heard by the patient in his head, and the operator, by approaching his ear to the catheter, may hear the crackling produced by the breaking of minute bubbles of gas. The electrolysis is kept up for four minutes, and usually before the expiration of that time, if it is possible that the obstruction can be removed, it will be found that the bougie can be pushed on for a small distance, sometimes for its full length. Generally on the first occasion the Eustachian tube is rather sensitive, but it seems to acquire toleration for the process, and at no time is so much discomfort experienced as might be expected. The operation has now been performed a large number of times without any unpleasant experiences, nor has the treatment caused any pain, either at the time or afterwards.

"In favourable cases there is an immediate improvement in the hearing, as tested by the greater distance at which a watch can be heard after the passage of the instrument; the distance at which it is heard may be doubled. In other cases the results are not so good, partly from the difficulty of reaching the Eustachian tube, and partly no doubt from other causes."

235. **Lachrymal obstruction.**—In a paper by Mr. Jessop and Dr. Steavenson,* an account is given of ten cases of lachrymal obstruction treated by electrolysis. The advantage of the method is again due to the ease with which the action can be confined to the exact

* *Brit. Med. Jour.*, 1887, ii., p. 371.

parts needing treatment. The instrument used by them is a platinum probe curved. The operation is very simple; the current required is small, two to four milli-ampères being sufficient, and the duration is thirty seconds. No anæsthetic is needed; the probe must always be negative, the positive pole being the usual pad indifferent electrode. Two or three sittings suffice to produce cure of the obstruction. The cases related are confined to those in which the obstruction was at the punctum or in the canaliculus, and not in the sac itself. The operation is simpler than the slitting up of the canaliculus, and the improvement is permanent.

236. **Electrolysis for uterine fibroids.**—Since the publication by Dr. Georges Apostoli of his method of treating fibro-myoma, an immense amount of literature has been produced on the subject. Much has been said both for and against Apostoli's* treatment, and the enthusiasm which was at first shown in his favour by many writers, has to a large extent been followed by a reaction against it. There is no doubt, however, that electrolysis may hold a place in the treatment of fibroids, because it offers an alternative to the very serious operation of abdominal section, and in many cases it affords great relief to the symptoms of the patient, even if it does not effect a radical cure of the disease. We propose here to give a short abstract of Dr. Carlet's† original paper, produced under the immediate direction of Dr. Apostoli.

The early attempts at treating fibroids by electrolysis were done by Cutter, 1871. Routh and Althaus, 1873.

* See the medical journals, 1888, 1889, and publications by Drs. Steavenson, Bartholow, Keith, Massey, Engelmann and many others.

† *Le traitement electrique des tumeurs fibreuses de l'uterus*, Dr. Lucien Carlet, Paris, 1884.

Brachet, 1875. Semeleder, 1876. Everett, 1878. Aimé Martin, 1879. Gallard, 1881. In 1882 Apostoli communicated a paper to the Académie de Médecine, in which he described his method of procedure. He recommended an internal positive electrode of platinum, and an abdominal electrode (negative) of moist china clay of large surface, and a continuous current of sixty to seventy milliampères, for from five to fifteen minutes. In certain cases when the internal electrode could not be passed into the cavity of the uterus, he thrust it through the cervix into the tissue of the uterus instead. Sittings once or twice a week. The action of the current was to produce destruction of the uterine mucous membrane. The results were to reduce the size of the uterus, and to decrease the hæmorrhage. The destruction of the mucous membrane is followed by a healthy process of repair, by a process of involution, and by a cicatrisation which checks the metrorrhagia.

Drs. Apostoli and Carlet arrange their account of the operation as follows:—

1. *The seat of the operation.*—It must be intra-uterine, and the internal electrode must occupy the whole depth of the uterine cavity. To puncture the uterus from the abdomen is dangerous, for suppuration and peritonitis are likely to follow, adhesions are likely to be formed, and the uterine mucous membrane is not touched.

2. *The nature of the operation.*—The positive pole is indicated for the internal electrode when hæmorrhage is the chief symptom, the negative pole may be used when the fibroids are large, hard and subperitoneal, and when there is not much hæmorrhage, for if anything it increases the tendency to bleeding.

The current must be quite uniform, and must be raised and lowered very gradually, sudden interrup-

tions with the large currents used are sufficient to give dangerous shocks.

3. *The strength of current.*—The maximum strength which the patient can bear is to be employed; when the uterus is large, a greater strength is needed to produce the same density of current (see § 106). Cauterization is easily obtained in an uterus of little length owing to the smaller surface for distribution of the current, but a much greater current is needed with a lengthened uterus, owing to its greater area. One hundred milliampères is the mean strength used by Apostoli since 1883 (date of Dr. Carlet's paper, 1884), and this is generally well borne by the uterus. In hysterical patients the current is not well borne, or rather a fit may threaten, unless the current is very cautiously increased. The operation must not be undertaken during acute perimetritis (or any other febrile condition).

4. *The duration of the operation.*—The mean duration should be from five to ten minutes, according to the gravity of the case and the tolerance of the patient. When patients have to return home immediately afterwards, five minutes suffices in most cases. A strong current for a shorter time is better than a lesser current for a longer time.

5. *The number of sittings.*—An absolute cure with complete restoration to health (*ad integrum*), is and will ever be, beyond our medical resources. Our hope is that we may reduce the size of the tumour by one-half or one-third, and remove the symptoms. Whether the tumours persist or not, the operator should persevere until the symptoms are relieved, and he ought not to be satisfied till this goal is reached. "He should depend on the general condition and statements of the patient, and not on what digital exploration reveals."

Twenty or thirty sittings is the mean number, but many patients declare themselves cured after five to ten sittings. "If after great amelioration the patient desires to gain all she can from the treatment, it may be resumed, but the progress will be much more slow than at the commencement."

6. *Choice of time.*—When pain and losses are not very great and other symptoms are not acute, choose the inter-menstrual period, but on the other hand, with serious symptoms making life miserable or endangering it, begin at once, even during severe bleeding.

The intervals between sittings should be long enough for all pain or discharge produced by the previous ones to have ceased. The operation may be performed once a week, or even twice a week if the patient is able to keep her bed or to remain very quiet.

7. *Technical details.*—Before commencing explain to the patient what is going to be done, make sure that the battery is in good order, and that all wires and connections are sound, disinfect the internal electrode, adapt the abdominal electrode of potter's clay carefully to the surface of the skin, first covering any little abrasion or acne spot, however small, with a piece of oiled silk or guttapercha tissue. The patient must remove her stays and loosen all her skirts, and the abdomen must be quite bare. She must recline on her back on a couch or across the bed, the vagina must be thoroughly syringed out; finally she must be assured that the operation will not be very painful, and that at the slightest sign from her the strength of current will be reduced, on the other hand she must be encouraged not to complain unnecessarily; place the clay electrode on the abdomen, see that its margins do not touch the groins or pubes, attach the battery wire, then introduce the

internal electrode with great care and gentleness. (This is the most difficult part of the operation, and it may be better to do it before applying the abdominal electrode). Make sure that it has passed to the full length of the uterus, examine to see that the vagina and vulva are perfectly shielded from metallic contacts, and encourage the patient to press with her palms upon the clay electrode, so as to keep it well applied. Do not commence the current till all pain from the introduction of the electrode has passed off. After the operation tell the woman that she will have pains for a few hours, and a slightly tinged discharge for a day or two. She must rest for two hours before going home, and must then lie down. Walking exercise is bad. Conjugal relations must be absolutely forbidden.

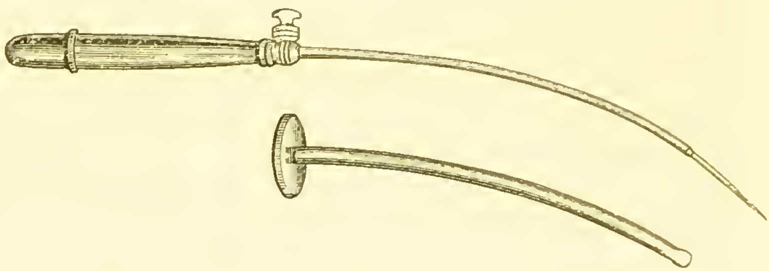


FIG. 85.—Apostoli's uterine electrode and sheath.

Weak injections of Condy's fluid or carbolic lotion should be used once daily.

The intra-uterine electrode has the shape of a sound, insulated except at its extremity, this part must be of platinum, and its length should be capable of adjustment to suit the length of the uterus. The insulation should reach sufficiently far to protect the cervix uteri as well as the vagina. Care must be taken that no bare metal touches the vulva, or the skin of the thighs, or a painful sore place will be produced.

Dr. Apostoli's sound (fig. 85) was fitted with a sliding vulcanite sheath; platinum pieces, either sharp or blunt, are screwed into the end of the shaft, and are chosen of a length to suit that of the uterine cavity. Subsequently Steavenson modified and improved the original pattern by making an electrode shaped like a hard rubber catheter with a platinum tip (fig. 86). The advantage of this shape is that the instrument is more flexible and more easily introduced into the uterus, and the insulation part is not thicker than the rest, therefore it can

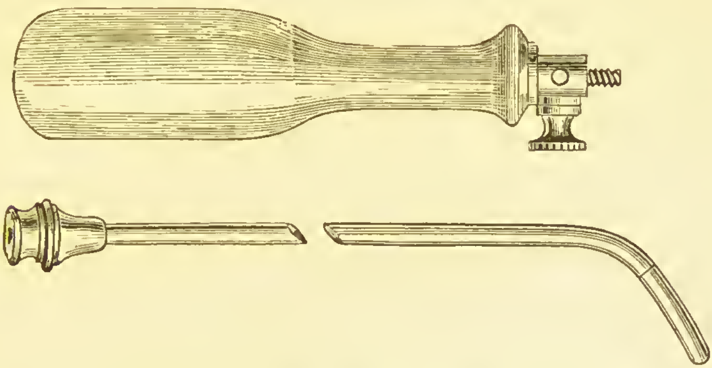


FIG. 86.—Steavenson's electrode for fibro-myoma.

enter more easily into the cervix so as to protect that part. If this form of electrode be used it will be necessary to have a set with platinum ends of different lengths, whereas Apostoli's sound can be altered to suit each case by means of changing the platinum points.

The electrodes with sharp points are made for puncturing the uterus when the cervical canal cannot be reached. Puncture, however, is now very rarely practised.

An ordinary uterine sound made with a platinum end and fitted with a binding screw answers the purpose very well; the stem can be insulated by a thin soft

rubber tube slipped over it, leaving bare the appropriate length at the end. The edge of this soft tube will enter the cervical canal quite well, especially if it be painted over with a little collodion to fix it. The advantage is that such an instrument can be kept absolutely clean, a new piece of rubber being slipped on for each operation and a little vaseline smeared over to protect against any possible escape of current through minute holes in the rubber.

The abdominal electrode is prepared by making up a putty like mass with the potter's clay and water, it is then spread out evenly on a piece of muslin in a layer half an inch thick. A metal plate with binding screw is embedded in its upper surface, and the muslin is folded over to enclose a round cake of the clay. It should measure about nine or ten inches in diameter.

The preparation of this electrode is rather troublesome, and it is heavy and rather messy for the patient, but it adapts itself well to the surface of the abdomen and gives good results. Substitutes for it have been devised, such as large flat bags of bladder or dialysing parchment containing warm water, for pads of wood pulp. These will also adapt themselves very closely. Metal plates covered with moistened flannel, or carbon in small lumps covered with flannel to form a cushion have also been tried.

A firm cake of gelatine also conducts very well, and is easily prepared by liquefying some gelatine and pouring out into a small plate, a metal pad can be fixed to it when it has set, by laying it on the surface and pouring more gelatine over it. It is rather sticky and unpleasant however, as it has a tendency to melt at the temperature of the body. The addition of one or two per cent. of alum, however, will prevent this, and im-

prove the pad, which is to be enclosed in muslin, and used exactly as the clay electrode. It is much more cleanly and agreeable.

In a communication on the use of electricity in gynæcology* Drs. Aust-Lawrence and Newnham, writing after its use in one hundred cases arrive at the following conclusions. In *Myoma* the results have been as follows :—" There has not been a very great reduction in the size of the tumours, but rapidly growing tumours have been checked in their growth in all instances except one. The bleeding has been lessened in a very marked manner by the intra-uterine use of the positive pole. The pain also has been lessened and in some cases removed entirely. The general health has been much improved, the feeling of weight has been relieved to a great extent, and this out of all proportion to the diminution in the size of the tumour."

They do not regard electricity as a means of cure or even of relief in all cases of myoma uteri; but consider it a very valuable addition to the means of treating a very troublesome set of cases.

They also mention a patient who continued to have profuse uterine hæmorrhage from a fibroid after removal of both appendages; the hæmorrhage was very much lessened by subsequent electrical treatment.

Bergonié and Boursier have published the notes of a hundred cases in which they carried out Apostoli's treatment for fibro-myoma, and they give the following summary of their views† :—" The electric treatment of fibro-myoma is undoubtedly efficacious as a palliative method of treatment. When hæmorrhage was the chief symptom complained of 90 per cent. were relieved.

* *British Medical Journal*, November, 1891.

† *Arch. d'Electricité medicalé*, 1893, 211.

The general state of health was improved in 79 per cent., the symptom of pain was relieved in 50 per cent., while a decrease in the size of the tumour was observed in ten per cent. only.

237. **Other uterine disorders.**—*Subinvolution.* Electrolysis has also been used by Dr. Aust-Lawrence for subinvolution. The intra-uterine application of the positive pole with a current of fifty milliampères given once a week for three or four times has a very good effect, the uterus very rapidly undergoing involution, but they are of opinion that when endometritis is present, other intra-uterine medication gives better results.

Stenosis of the cervix can be removed by electrolysis very much in the same way as in the treatment of stricture. Five or ten milliampères for a few minutes usually suffice to enlarge the canal of the cervix. Several electrodes of different sizes may be required, the gain in calibre is said to be permanent.

Dysmenorrhœa and Menorrhagia.—The caustic action of the negative pole has been tried for membranous dysmenorrhœa, the method is exactly the same as that used for fibroids, and menorrhagia apart from fibroids has been similarly treated by the positive pole.

238. **Extra-uterine fœtation.**—Attempts have been made to arrest the progress of extra-uterine fœtation by electrical treatment, and cases which appear to have been successful have been recorded, most of them in America. At the meeting of the British Medical Association at Brighton, in 1886, Dr Aveling and Dr. Petch both made communications on the subject, each reporting one successful case, the former treated his patient, whose pregnancy had lasted three months, by induction coil currents, which do not seem to have been at all powerful; one pole was placed on the abdominal

surface and the other in the vagina so that the tumour was included between them, after three sittings the tumour began to diminish and the patient made a good recovery. Dr. Petch's patient had been pregnant for about six months, and the fœtal heart sounds were audible. Two needles were introduced through the abdominal wall, one at either end of the tumour, they were insulated except for three quarters of an inch at their points, and a current from thirty Leclanché cells was passed for one hour,* the mother was not anæsthetised, and felt only slight pain, the heart sounds were not affected at the time, but four days later they had ceased. The patient made a good recovery and had continued well for two or three years since the operation. In the discussion which followed the reading of these papers several speakers related cases of a similar kind which had occurred to themselves, and the generally expressed opinion was that electrical treatment might be useful when extra-uterine pregnancy could be diagnosed before the end of the third or fourth month, and before rupture of the tube had taken place; when the pregnancy was farther advanced, electricity was not so valuable, because even if the fœtus could be destroyed by its means, there was still considerable risk to the mother of septic poisoning from the retention of the dead fœtus, and it was not likely to undergo absorption, although in Dr. Petch's case the tumour, a fœtus at six months, had been reabsorbed without accident. On these grounds Mr. Lawson Tait emphatically condemned the use of electricity, and because it was extremely difficult to diagnose the tubal pregnancy before rupture, he considered that abdominal section was far preferable.

* Probably about 200 milliampères.

In the St. Bartholomew's Hospital Reports, vol. xix., 1883, Dr. Matthews Duncan and Dr. Mason have published a paper on extra-uterine fœtation, with an account of one case in which electrolysis had been tried; the pregnancy had lasted five months and the fœtal heart was audible. Electrolysis was practised on two occasions with a fortnight's interval. The current of forty cells was employed for six minutes, on the first occasion the poles were in the vagina and on the abdomen respectively; on the second occasion two needles connected with the negative pole were thrust into the tumour while the positive was applied to the abdominal surface as before.

The fœtal heart was not arrested on either occasion. Other means of destroying the fœtus were then employed, and the patient died of peritonitis a week after the second sitting; post-mortem the fœtus was found very considerably macerated, this was considered to have been due to the electrical treatment.

Dr. Percy Boulton* has published a case of early (six or eight weeks) extra-uterine fœtation, where electrolysis proved fatal from peritonitis, but there was no post-mortem examination to show what changes had been set up in the tumour. The case shows that electrolysis, even in the early months, is not free from danger.

Mr. Lawson Tait and other speakers at the Brighton meeting pointed out that very often tubal pregnancy may undergo spontaneous cure. It is very likely that some of those said to have been cured by induction coil shocks were really cases of this kind, because it is difficult to see how a moderate induction current, diffused through the large sectional area of the abdomen, could

* *Brit. Med. Journal*, April, 1887.

exert any effect at all upon the tissues of a young fœtus, though it might possibly produce some mechanical compression by setting up tonic contraction of the muscle fibres in the Fallopian tube round it. To slay even a small animal it is necessary to have very large currents, carefully concentrated upon a vital part. A fœtus lying in the midst of the conducting tissues of the abdomen could only receive a small fraction of the comparatively small current yielded by a medical coil.

239. **Cancer.**—The destruction of cancerous tumours by electrolysis has been proposed.

Although it is not likely that electrolytic treatment will do more than produce sloughing of parts of a cancer, yet it is sometimes useful, when nothing else can be done, because the pain of the cancer is often much diminished after electrolysis, as has been observed by Althaus. Cures of cancer by electrolysis will be found reported in many of the books on electrical treatment, but a close study will usually reveal some weak point in the history of the cases related.

CHAPTER XIV.

Cautery and Lighting Instruments.

The galvano-cautery. Batteries for cautery purposes. Accumulators. Wires and leads. Lamps. Batteries for lamps. The use of electric light mains. Rheostats. The cystoscope. The panelectroscope. The electro-magnet.

240. **The galvanic cautery.**—The forms of galvano-cautery in common use are numerous, but their plan of construction depends upon one general principle. The cauteries used for small operations consist of small loops of platinum wire mounted on straight or curved copper supports, which are insulated from each other, and then bound together to form a convenient stem (fig. 87).

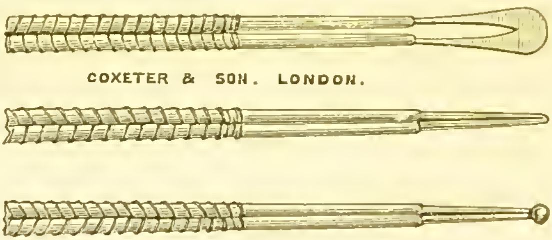


Fig. 87.

These fit into a handle provided with binding screws and a key for easily opening and closing the circuit. The platinum loops, having a relatively high resistance, become heated by the passage of the current. The figure (fig. 88) shows an usual form of handle, known as Schech's.

The shorter handles are more convenient than the large size, which is more expensive, and too unwieldy for delicate manipulations.

If the cautery mounts are too slender, they will become heated; the current, therefore, should only be left on when the cautery is in actual use. They are insulated by a thick waxed thread twisted round them in

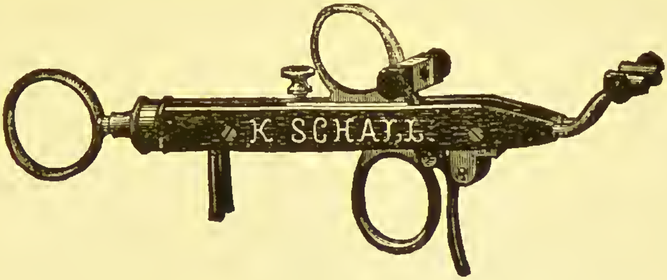


FIG. 88.—Schech's universal cautery handle.

racking turns, which keeps them from touching, although binding them together, and forms a sufficient means of insulation, except when they become overheated.

FIG. 89.—Cautery for larger incandescent surface.

Besides the simple platinum loops, cutting instruments of various shapes are made by hammering the platinum flat or by bending it in various ways. Where a larger incandescent surface is required, a loop or spiral of platinum supported in grooves on a porcelain mount is made, the porcelain then becomes heated to redness as well as the platinum (see fig. 89). Different thicknesses of platinum wire are used, and accordingly the current required varies greatly in different cauteries.

Sometimes a long loop of wire is used as an ecraseur, being adapted cold to the part to be removed, and then heated, and a screw can be mounted on the handle

figured above for gradually drawing up the wire loop (fig. 90). It is as well to mention that the temperature of a cautery must never be allowed to rise above dull redness. At a white heat the cauterising action is so rapid that searing of the surface does not take place,

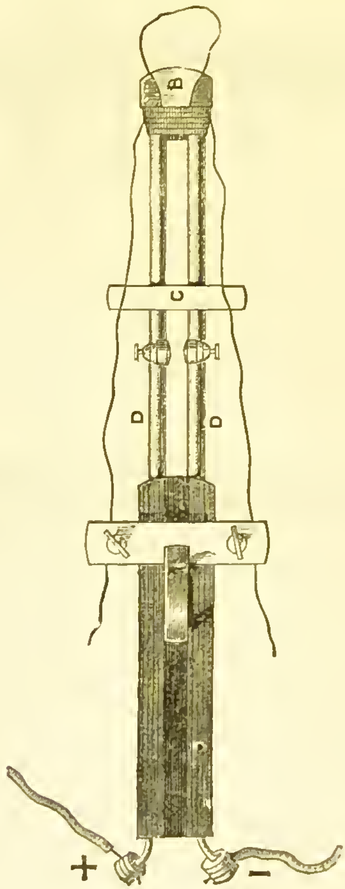


FIG. 90.—Galvanic ecraseur.

and hæmorrhage may follow as profusely as after division of the tissues by a knife. A large number of modified forms of cautery and mount will be found in the

instrument makers' catalogues. The resistance of the cauteries just described may vary from ·025 to ·04 ohm.

The current required varies between eight or ten ampères for the smallest, to upwards of twenty for the larger ones.

Still larger currents are required for a few cauteries, which have been constructed for special purposes.

In the prostatic cautery of Prof. Bottini* the part to be heated consists of two strips of platinum, each 20 mm. × 8 mm., which lie side by side in the concavity near the beak of an instrument, which is shaped like a vesical sound. The current passes along one strip and returns by the other. The large mass of the platinum makes the resistance of the part to be heated remarkably low, about ·0005 ohm, and consequently an immense current, amounting to fifty ampères, is required to raise it to a red heat. Such a current as this taxes any portable battery to the utmost. This instrument is used for the radical cure of the symptoms caused by enlarged prostate, and its use has been advocated in this country by Mr. Bruce Clarke,† who has employed it successfully on several occasions.

The current passes through the instrument to reach the platinum strips, the metal tube itself forming one conductor, with an insulated return wire down its centre, the rest of the space inside the tube being used as a channel through which water is circulated to keep the stem of the instrument cool. The return wire is barely able to carry the large current, and offers considerable resistance, this increases the difficulty of heating the platinum.

* *Brit. Med. Journal*, 1891, vol. i., p. 1121. Description and figure.

† *Proceedings of the Medical and Chirurgical Society*, Jan., 1892.

241. **Cautery batteries.**—The batteries of small

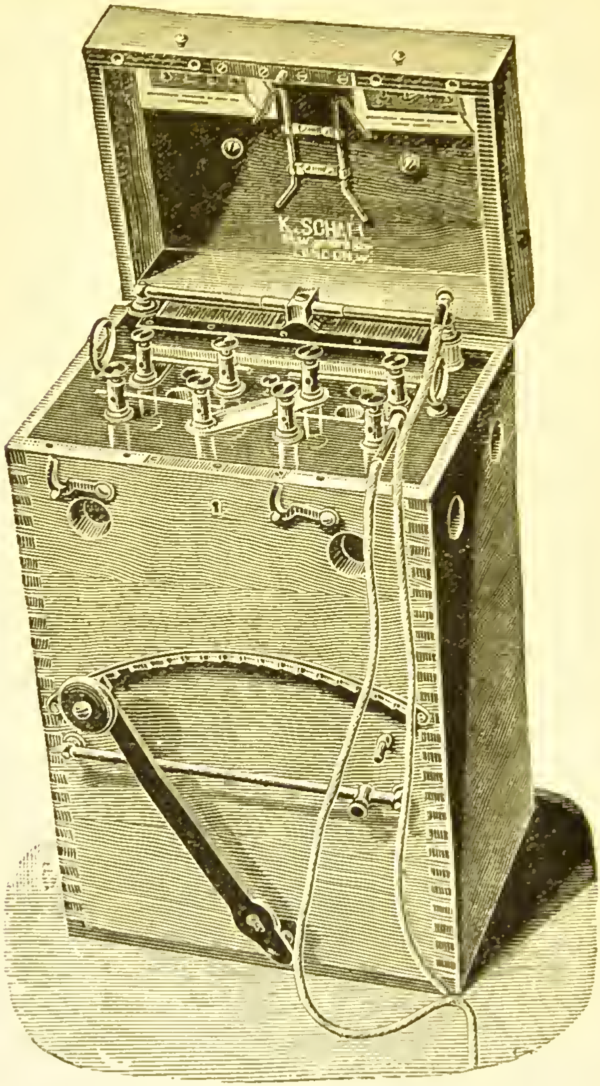


FIG. 91.—Bichromate battery for electric lamps and galvano-cautery.

cells which are used in medical treatment are arranged

for high electromotive forces with the minimum of weight, and their internal resistance is of little importance. For cautery purposes the conditions are quite different, and the small medical cells are therefore unsuitable. Large bichromate cells have been much used for cautery purposes, but they are rather untrustworthy, although they may be made to yield a large current for a brief period. From their tendency to rapid polarisation they are apt to fail suddenly in use. Fig. 91 shows a form of this battery which is strong and good, and may be easily arranged as a two cell battery with pairs of cells in parallel for cautery purposes, or as a four cell battery for electric lamps (see § 50).

By far the most convenient form of battery for cautery and lamp work is an accumulator, they do not polarise, and therefore they give a steady current, their internal resistance is very small, their capacity (§ 63) is large, and they will keep in good order for two or three months without attention. With proper care in use (p. 73) they are perfectly trustworthy. They are heavy, but not more so than any other cautery battery. The Electrical Power Storage Company prepare small two cell accumulators for medical purposes, weighing from thirty to forty pounds, with three or five plates in each cell. These will heat all ordinary cauteries fairly well, though it is rather a strain upon them, the larger size with five plates is therefore more preferable. Still for the brief periods during which the cautery is required the three plate cells will suffice, but if much heavy work is required to be done the larger sizes are the best. At present there is a tendency to return to the original Planté type of secondary cell (§ 63), as it has the advantage over pasted plates that it is not damaged by a high rate of discharge, and they will probably prove to

be superior for surgical uses. As at present made, they are rather heavier than the E. P. S. cells.

The most convenient outfit for cautery and surgical lamps is a four celled accumulator, with a switch for re-arranging the cells in two pairs in parallel, this can then be used as a two cell accumulator of double cells

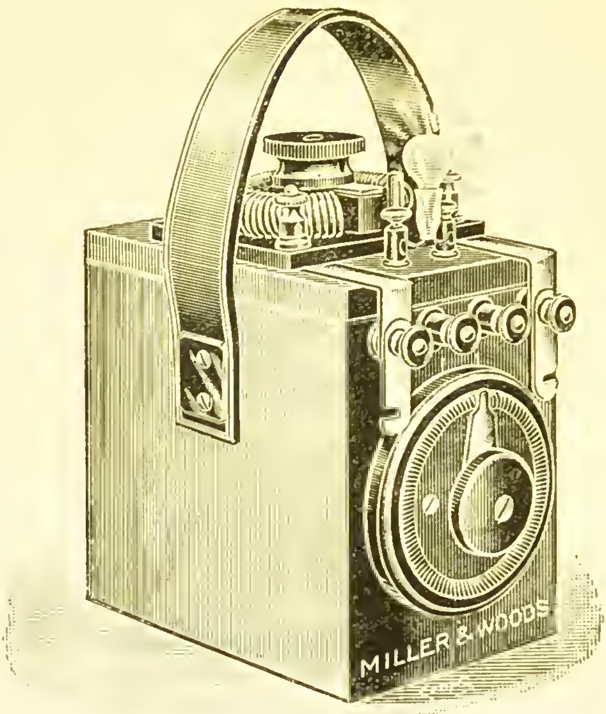


FIG. 92.—Accumulator for lamps and cauteries.

for cautery purposes, or as a four celled one for lamps taking up to eight volts. Fig. 92 shows such an apparatus, which I have had constructed for this purpose. It weighs fifteen pounds, and is provided with two rheostats, one for lamp and one for cautery use. It measures 7 × 4 × 5 inches, and is to be obtained

from Messrs. Miller and Woods, 2 Grays Inn Road, Holborn, W.C.

242. **Electric light mains.**—In §§ 74, 75 the use of electric lighting mains for medical purposes was discussed. When they are to be employed for small surgical lamps or for cauteries, certain points are important, and will therefore now be considered. With the alternate current supply a transformer should always be used, and it should be capable of adjustment to suit the exact pressure needed for the lamp or cautery to be used. This can be done by a proper make of transformer, or by means of an accessory resistance. There is no difficulty in obtaining what is required, and the illustrations in the above paragraphs will serve as a guide in choosing one.

On the direct current supplies the mains may be used to charge an accumulator, and this can be subsequently used for the lamp or cautery. This is also quite a simple matter, and has been already dealt with (§ 74). For small lamps an adjustable resistance direct on these mains is comparatively unobjectionable. When it is proposed to heat a cautery from the mains direct, the matter becomes much more difficult to carry out. A cautery requires ten ampères or more to bring it to redness, and a current of this magnitude is quite sufficient to maintain an arc if from any cause the platinum of the cautery should break or fuse during its use. The unexpected establishment of an arc during cauterisation of a patient might have serious consequences.

The risk of such an accident can only be avoided by having two parallel circuits from the positive to the negative main, one to carry the cautery and the other to act as a bye-pass in case of accidental fusing or

fracture of the cautery wire. No arc need then be feared, but the apparatus expends energy at the rate of about two-horse power while it is in action, and special main wires and fuses are required to carry the current. As each branch may have to carry upwards of ten ampères when the cautery is at work, they must be constructed in a substantial manner to stand that magnitude of current.

A properly designed apparatus for this purpose is in use at some of the London hospitals, and works well. Mr. Miller, who designed it, writes as follows:—"The apparatus we have fixed up has been in use for over a year and gives satisfaction. We see no other way of doing what is wanted, and for hospital use it is perhaps

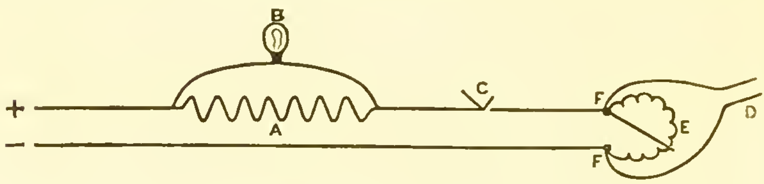


FIG. 93.—Arrangement of wires for cautery on continuous current mains.

better than accumulators. A red lamp burns whenever the current flows, so that there is no excuse for wasting current."

A diagram of the connections is as follows:—A on the positive main represents a strongly made resistance of about five ohms. B is a red lamp. C switch. D wires to cautery. E bye-pass, its exact resistance being varied by the moving arm, which is used as the regulator (fig. 93).

With this apparatus a current of about twenty ampères traverses the circuit when the switch is on. At FF the circuit divides, passing either through a resistance E, or through both E and the cautery D

The amount going by each route is adjusted by the moving arm, which can travel along E.

In this way the tendency to an arc is got rid of, and there is very much less sparking and burning at the contact in the handle of the cautery.

243. **Conductors.**—It is important to use thick copper wire conductors for the cautery, because in this case the resistance of the whole circuit being very low, that of the conductors becomes an important fraction of it, and may determine whether the cautery will be properly heated or not.

It may be useful to give an example here of the calculations to be made in arranging the apparatus for heating a cautery. Suppose that a cautery having a resistance of ·04 ohm and requiring a current of 20 ampères is to be heated, and that the battery power available consists of two accumulator cells in series, each with an electromotive force of two volts, the internal resistance of each cell being ·01 ohm.

To obtain a current of twenty ampères from four volts the total resistance in circuit may amount to ·2 ohm. If proper leads are used, their resistance will be ·0014 ohm per metre. We will suppose each wire to be 1·5 metres in length, their total resistance will then be ·0042 ohm. The necessary resistances in circuit in this case (resistance of battery, of leads, and of cautery) therefore amount to $\cdot 02 + \cdot 0042 + \cdot 04 = \cdot 0642$, or say ·065 ohm. This leaves a margin for faulty contacts and for rheostat of ·135 ohm, and the cautery would be adequately and easily heated. For the kind of rheostat used with cautery see the upper part of fig. 92.

But now suppose that the leads are of a size having a resistance of ·04 ohm per metre. This will give a total resistance in circuit of $\cdot 02 + \cdot 12 + \cdot 04 = \cdot 18$ ohm, leaving

a bare margin of ·02 ohm for faulty contacts. This would certainly be insufficient, as there are several points of contact and a small degree of oxidation or tarnishing at any one of them would be sufficient to prevent the cautery from heating, add to which there would in all probability be a considerable amount of heating in the leads, which would certainly increase their resistance, and might destroy their insulation. These examples show the importance of using stout conducting wires with plenty of copper in them, and of keeping all contacts and binding screws scrupulously clean and bright. A rheostat must always be included in the circuit when a cautery is to be heated, if this precaution is neglected, there will be much trouble from over-heating and fusing of the platinum loops.

244. **Surgical lamps.**—Small incandescent lamps have been adapted to laryngoscopes, ophthalmoscopes,

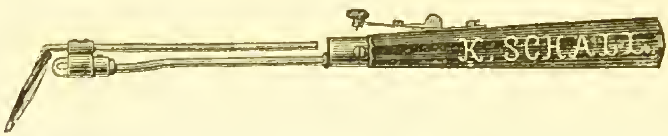


FIG. 94.—Laryngoscope, with electric lamp.

endoscopes, vaginal specula, and other instruments (figs. 94, 95). They are not used very universally, because in many cases the maintenance of the battery is troublesome, and because other sources of illumination are sufficient.

Lamps are also made to fix to the head for light during operations. A very good small lamp is made by Beddoe of Nine Elms Lane, S.W., and was described and figured in *British Medical Journal*, Dec. 1892, by Mr. Washington Isaacs. It throws a small parallel

beam, and is made on correct scientific principles. It weighs only half an ounce.

These small lamps are of about one candle power and vary a good deal in their resistance (5-20 ohms), and therefore the electromotive force required to bring them to incandescence varies also. If the filament is slender, or if it is long, their resistance is high, if it is short or thick, their resistance is less high. A long slender filament may require eight or ten volts to light it properly, while a shorter one will glow with six volts. The rate of consumption of energy by an incandescent lamp is about four Watts per candle. Thus if a ten volt lamp absorbs ·4 of an ampère, a six volt lamp would require ·7 ampère to give the same light. When the current is supplied from a portable battery it is best to use the higher voltage lamp for the sake of the advantage of having to provide a smaller current, 400 milliampères, ·4 ampère being more within the range of a portable battery than 700 milliampères, and the battery will therefore run down much less rapidly. On the other hand a greater number of cells will be required to provide the higher voltage.

FIG. 95.—Ophthalmoscope, with electric lamp.

Batteries most useful for lighting small lamps have been mentioned on page 83. Of these the bichromate cells are convenient if no means of recharging ac-

cumulators are available. Hellesen's dry cell may be used for this purpose, but does not keep well nor last long if used much for lamps. Six or eight dry cells of this make are fitted up in a plain oak box by Mr. Schall with a simple form of rheostat, and they may be trusted for a fair number of examinations. It is wise in choosing a battery of this kind to have the cells as large as possible, that renewals may not be required too frequently.

If accumulators are used, small ones may be had for the sake of portability. Small accumulators are put up by several electrical engineers for lighting the fairy lamps worn upon the stage, and these serve well for surgical lamps (see figures 16 and 92). The small sizes naturally require recharging more often than the large ones, but this is not an objection, because all accumulators are better for being recharged once every six or eight weeks, and the capacity of the small cells is sufficient for lighting a cystoscope or similar lamp for about twenty hours. This will allow of the use of the lamp for an hour and a half per week for three months, which is quite as much as is likely to be required. If wished the small accumulators can be recharged at home from a few cells of any good primary battery (§ 66), but in most towns nowadays there are facilities for recharging accumulator cells from a dynamo or central station.

245. **Rheostats.**—We have already said that the lamps vary in their resistance very widely, and a variable resistance in the circuit is the most convenient method of compensating for these variations, without it some lamps would be overheated and would quickly be destroyed. Rheostats of convenient size can be had ready fitted with many of the types of portable accumulator now in the market. The resistance required for

regulating the lamps need not be more than about six or eight ohms. As the current to be carried is only about half an ampère in a well made lamp the resistance is easily made of a few turns of fine german silver wire. Rheostats are equally important for cauteries, but there they have to carry large currents and must be made of thick wire; however, their total resistance need not be so great, for a variable resistance of half an ohm is sufficient to modify very greatly the current in a cautery circuit. (§ 243).

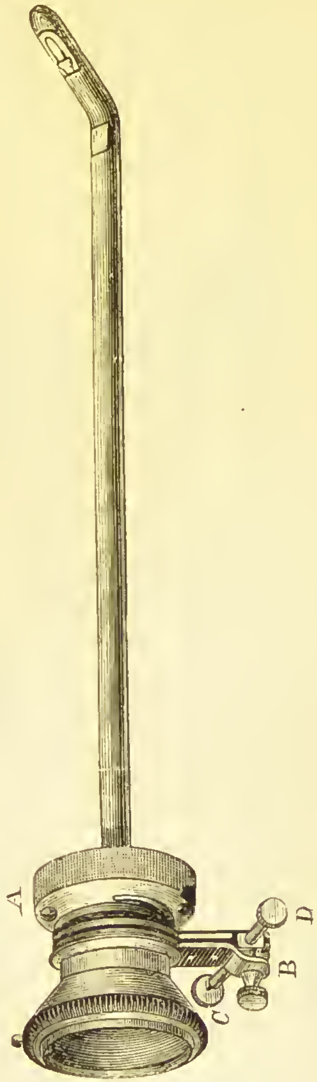


FIG. 96.—Cystoscope.

246. **The cystoscope.**—This is an instrument for examining the mucous membrane of the bladder, and it is perhaps the most important and useful of all the electric lamp instruments, because it affords information which cannot be obtained without it. The cystoscope (figs. 96-98) consists of a beaked sound, in which there is a telescopic arrangement by which the surface of the bladder is viewed through a small window of rock crystal. The lamp *L* is enclosed in the beak of the instrument and throws its light through another window,

also of crystal, *CF*, upon that part of the bladder wall which is in the field of view of the telescope. *B* is a screw for making contact, the wires are fastened at *CD*, fig. 96. For examining the upper part of the bladder a separate instrument with a small reflecting prism is used. A certain amount of practice is required to use the cystoscope properly, and to recognise the appearances of the mucous membrane of the bladder in health and in its various morbid conditions. With the dummy bladder (fig. 98) the necessary skill can be quickly picked up. For a full account of the instrument and mode of using it, see Mr. Hurry Fenwick's book on *The Electric Illumination of the Bladder and Urethra.** An anæsthetic

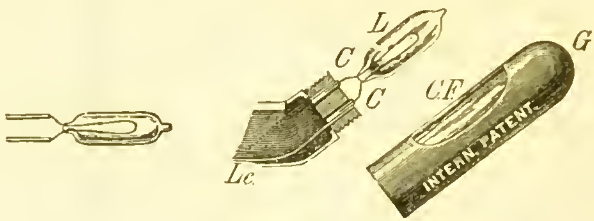


FIG. 97.—Arrangement of lamp in cystoscope.
L. Lamp. *CC*. Attachment to instrument. *CF*. Window in cap of instrument.

is not absolutely necessary for a cystoscopic examination, but it is more convenient to employ one, though cocaine may be made to do. The bladder must contain six or eight ounces of clear urine or clear water if a proper view of its walls is to be obtained.

If the fluid present be even slightly turbid, the view is very much obscured; and if necessary the bladder must be washed out with warm boracic lotion until quite clear. If too little fluid be present in the bladder, the beak of the instrument with the lamp is likely to

* London. J. & A. Churchill.

become buried in the folds of the mucous membrane, and there will be no light. Moreover, in that case the mucous membrane may be burned.

When the bladder contains eight ounces of clear fluid the end of the cystoscope lies free in the cavity, and the lamp is kept cool by the circulation of the water. The instrument must be pushed well home into the bladder

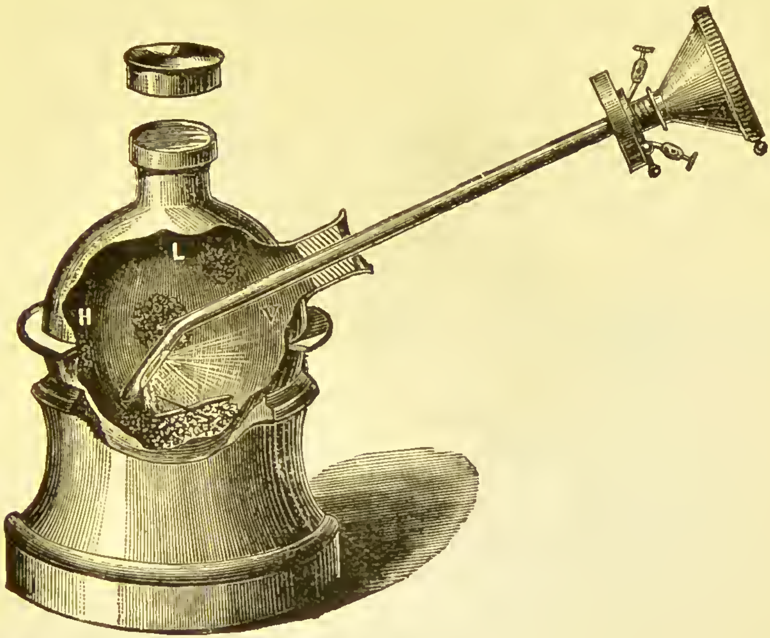


FIG. 98.—Cystoscope and dummy bladder.

and kept there; if it be allowed to work out at all, the beak may become engaged in the prostate, and then nothing will be seen and the prostate may be burned. The heat of the lamp is unimportant when it is surrounded by a volume of water, but when the lamp lies close against the mucous membrane there is no circulation of fluid round it, and it gradually grows hot and may burn if held too long in one place.

247. **The panelectroscope.** — Another universal lighting apparatus has been introduced by Leiter, of Vienna, under this name. It consists of a lantern with a handle and mirror, the light from a small incandescent lamp is projected by the mirror along a tube, which is inserted into the part to be examined. Tubes of various sizes are adapted to the instrument. It is especially useful for endoscopy of the urethra, but is also arranged for examining the ear, the pharynx, the stomach, &c.

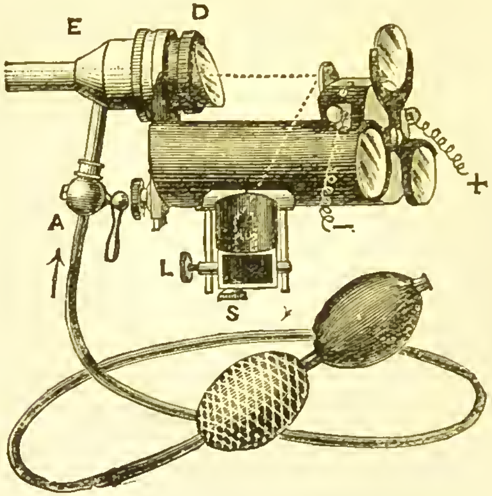


FIG. 99.—Panelectroscope (handle not shown).

For a figure and description of the instrument, see Mr. Hurry Fenwick's account in the *British Medical Journal*, 1881, vol. i., p. 462, and for a full account of the method of using it for examining the urethra, and of the appearances of the different morbid states, see his book already quoted in the last paragraph.

Another convenient lamp for abdominal surgery is shown in fig. 100. It is designed in such a way as to be kept clean and aseptic without any difficulty. It may be left in the antiseptic solution until required for

use. The attachment to the leads is by a double socket fitting, one wire making contact with the periphery of the tube which carries the lamp, and the other with an insulated lead passing down the centre. The enclosing tube of glass prevents any burning of the tissues with which it might come in contact during an operation.

The exploration of the antrum of Highmore by means of a lamp placed in the mouth, has excited a considerable amount of interest since the publication by Heryng* of his paper on the subject. The patient must be in a perfectly darkened room, the lamp is introduced into his mouth, and the lips are closed over its stem; when the current is then turned on the face becomes lighted up by a red glow. If one antrum contain pus a dark

FIG. 100.—Lamp for abdominal operations.

shadow is seen on the corresponding side, which is most perceptible just below the eye. A properly arranged lamp is made for the purpose by Mr. Schall. It should have an illuminating power of three or four candles.

The same method of trans-illumination has been employed for detecting deep-seated pus in other parts of the body; it has even been said that by means of a light in the bladder the contours of the abdominal viscera have been traced out. The diffusion of the light through the tissues, however, does not permit of

* *Berlin Klin. Wochens.*, No. 25, Sep. 2nd, 1889. "L'éclairage électrique de l'Antre de Higmore dans le cas d'Empyème." See also "De l'Empyeme latent de l'antre de Highmore; Dr. Jeanty." Bordeaux, 1891, Feret et fils.

GG.

seeing very much of their details. Even the bones cannot be clearly seen when trans-illuminated in this way, as may be readily tried by holding a lamp in the closed hand in a dark room.

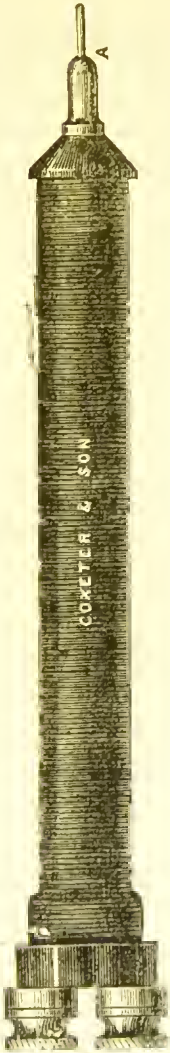


FIG. 101.—Electro-magnet.

248. **The electro-magnet.** — In certain cases this instrument is very valuable for the removal of fragments of iron or steel from the various parts of the body, especially from the eye. Permanent magnets can also be used.

Mr. Simeon Snell* has made large use of the electro-magnet, and has had great success with it. If the particle of iron be very small, or if it be fixed at all firmly in the tissues a magnet is not likely to remove it. But if the piece of metal be larger, and if it be lying loose, as, for example, in the interior of the eye, it may be withdrawn most successfully by a magnet introduced through a small incision.

One form of the instrument is figured here (fig. 101), several interchangeable pole pieces of different shapes and sizes are generally supplied, the most suitable one for each case can be screwed on at A as required. A few cells of any battery will suffice to excite the electro-magnet. It is sometimes useful to

* *The Electro-Magnet in Ophthalmic Surgery*, and *Brit. Med. Jour.*, 1883, vol. ii.

magnetise it by closing the current circuit after it has been placed in position near to the piece of iron. This is done in the instrument here figured by pressing down the small projecting slip of metal seen on the surface of the coils. The sudden magnetization then tends to jerk the piece of metal away from its bed. The vitreous humour will yield and allow the piece of iron to come forward to the magnet. In firmer tissues it is not always possible to extract it by an electro-magnet, for naturally it cannot hold the particle as firmly as it would be held by any kind of forceps. A large number of communications on the electro-magnet in surgery will be found in the medical journals.

Another use of magnetism in surgery is for the detection of buried pieces of iron or steel. For this purpose a freely suspended magnetic compass needle is used. When this is approached to a piece of iron or steel a deflection of the needle is produced. It is not of great value, practically. Cases where successful results have been obtained have been published from time to time in the journals, for which see Neale, *Medical Digest.*

There are many risks of fallacy in using a magnetic needle for the detection of pieces of iron. An iron bedstead, a steel truss worn by the patient or the operator, a pocket knife or other article of steel may act as a disturbing element, and if unsuspected may puzzle the operator hopelessly.

The induction balance of Professor Hughes might be of value in certain cases as a means of detecting buried pieces of metal. It has the advantage over a magnetic needle that it will give indications of the presence of other metals besides iron.

DESCRIPTION OF PLATES.

PLATES I.—VI.

The Motor Points.

PLATE.	
I.	THE HEAD AND NECK.
II.	THE UPPER LIMB (*back*).
III.	THE UPPER LIMB (*front*).
IV.	THE THIGH (*front*).
V.	THE THIGH AND LEG (*back*).
VI.	THE LEG AND FOOT (*outer side*).

PLATES VII.—XI.

The Cutaneous Nerves.

VII.	THE HEAD AND NECK.
VIII.	THE UPPER LIMB (*back*).
IX.	THE UPPER LIMB (*front*).
X.	THE LOWER LIMB (*front*).
XI.	THE LOWER LIMB (*back*).

PLATE I.

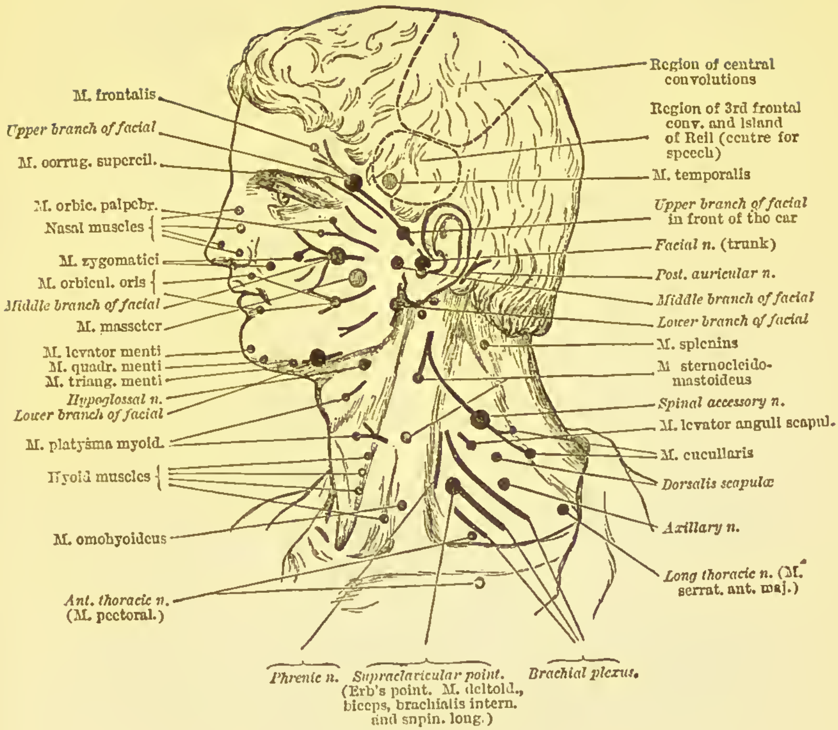
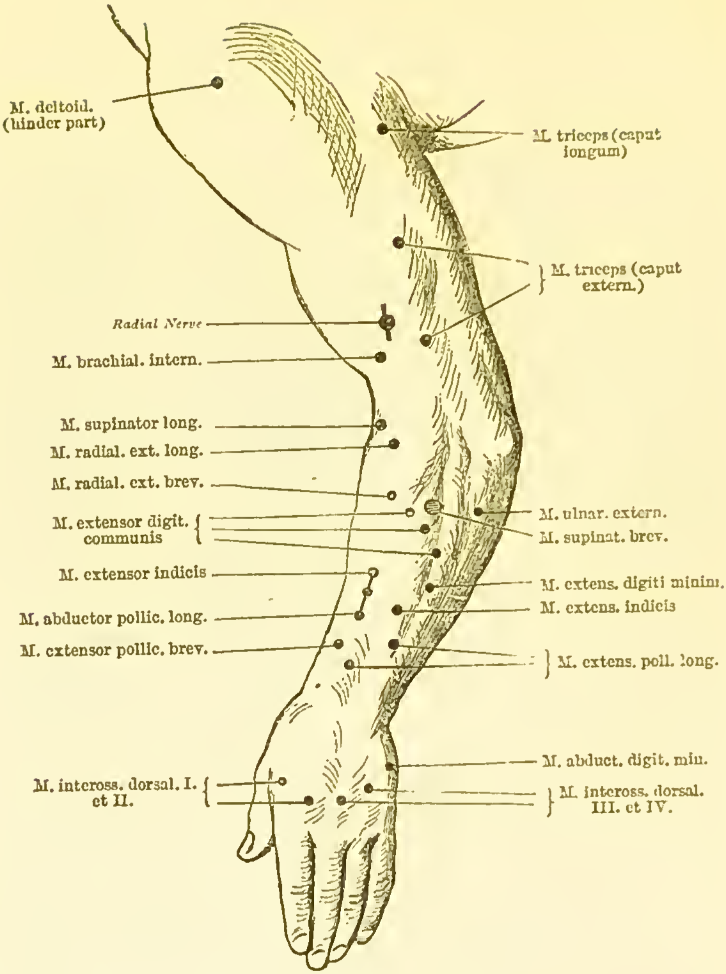
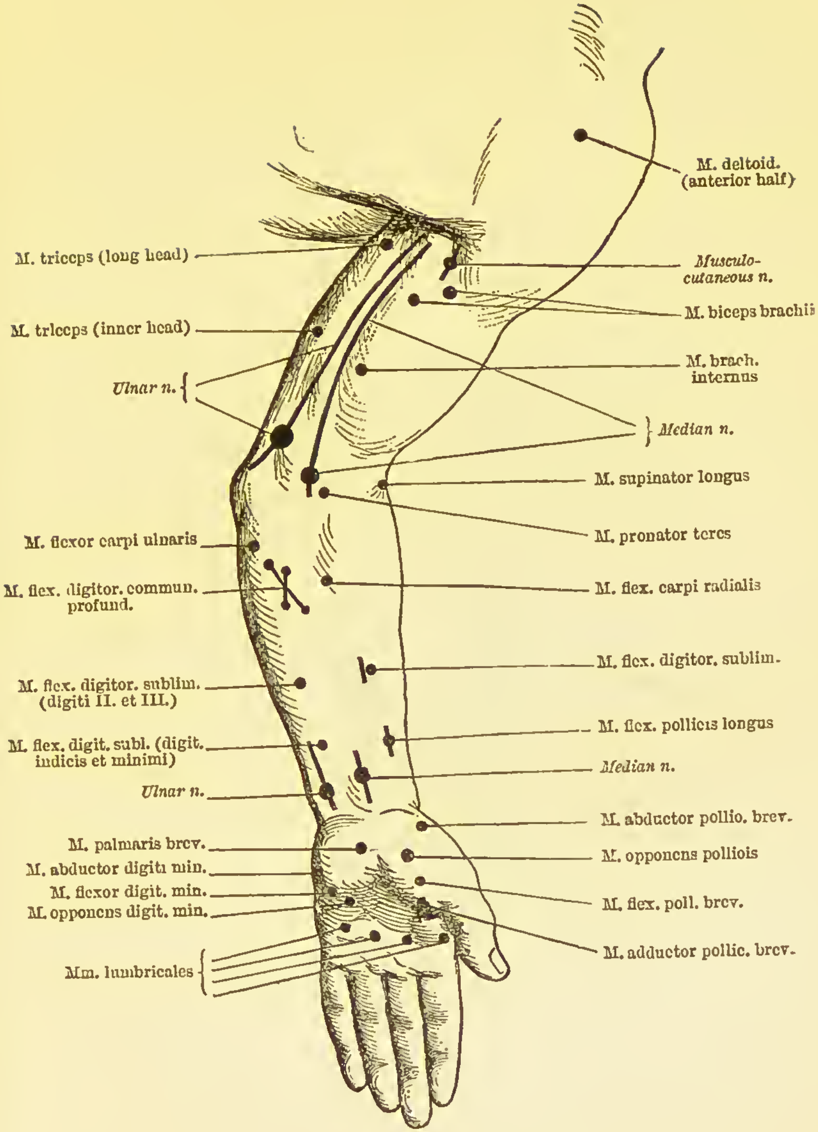

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n.
(M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and Island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapul.
M. cucullaris
Dorsalis scapulæ
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point.
(Erb's point. M. deltoid., biceps, brachialis intern. and supin. long.)
Brachial plexus.

PLATE II.



M. deltoid. (hinder part)
M. triceps (caput longum)
M. triceps (caput extern.)
Radial Nerve
M. brachial. intern.
M. supinator long.
M. radial. ext. long.
M. radial. ext. brev.
M. extensor digit. communis
M. ulnar. extern.
M. supinat. brev.
M. extensor indicis
M. extens. digiti minim.
M. abductor pollic. long.
M. extens. indicis
M. extensor pollic. brev.
M. extens. poll. long.
M. abduct. digit. min.
M. inteross. dorsal. I. et II.
M. inteross. dorsal. III. et IV.

PLATE III.



M. deltoid. (anterior half)
M. triceps (long head)
Musculo-cutaneous n.
M. biceps brachii
M. triceps (inner head)
M. brach. internus
Ulnar n.
Median n.
M. supinator longus
M. pronator teres
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. pollicis longus
M. flex. digit. subl. (digit. indicis et minimi)
Median n.
Ulnar n.
M. abductor pollic. brev.
M. palmaris brev.
M. opponens pollicis
M. abductor digiti min.
M. flexor digit. min.
M. flex. poll. brev.
M. opponens digit. min.
M. adductor pollic. brev.
Mm. lumbricales

PLATE IV

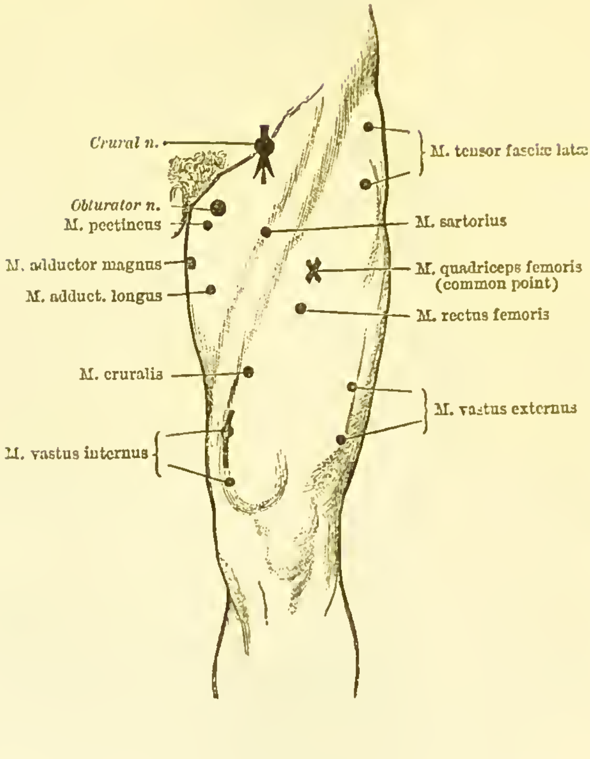
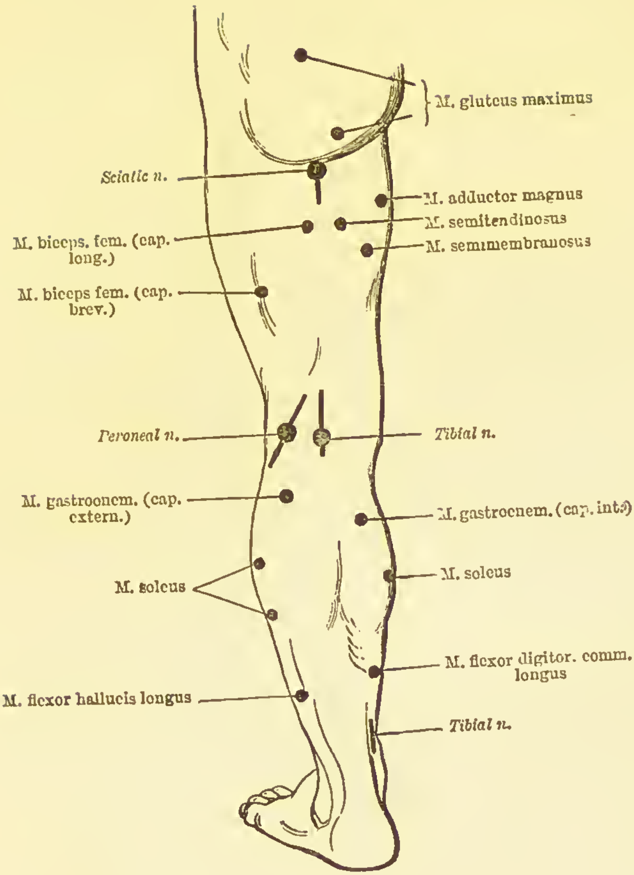
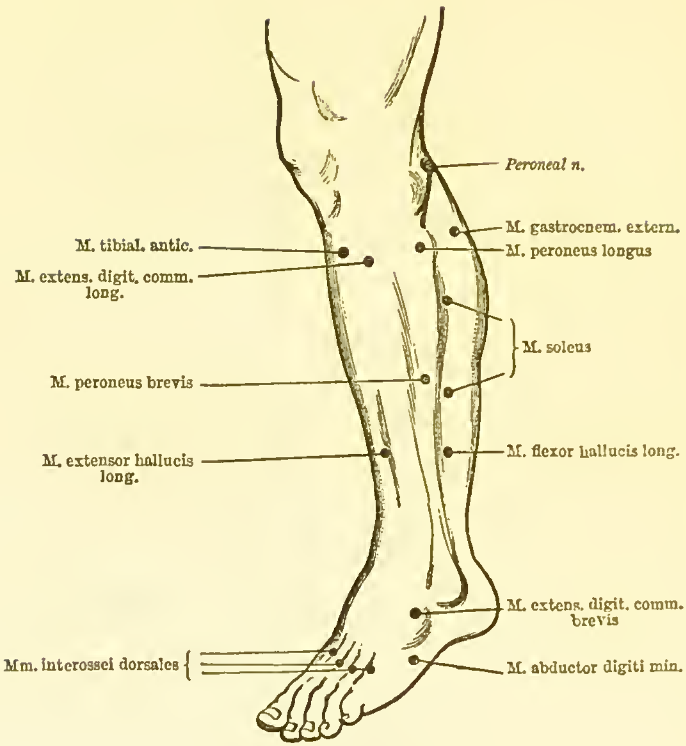

Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. adduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ latæ
M. sartorius
M. quadriceps femoris
(common point)
M. rectus femoris
M. vastus externus

PLATE V.



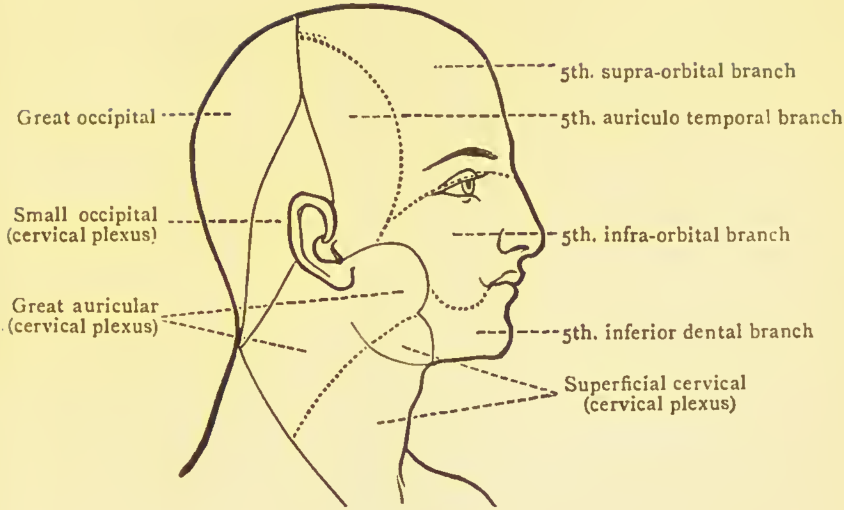
M. gluteus maximus
Sciatic n.
M. adductor magnus
M. semitendinosus
M. biceps. fem. (cap. long.)
M. semimembranosus
M. biceps fem. (cap. brev.)
Peroneal n.
Tibial n.
M. gastroonem. (cap. extern.)
M. gastrocnem. (cap. int.)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

PLATE VI.



Peroneal n.
M. gastrocnem. extern.
M. tibial. antic.
M. peroneus longus
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. extensor hallucis long.
M. flexor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VII.



Great occipital
Small occipital (cervical plexus)
Great auricular (cervical plexus)
5th. supra-orbital branch
5th. auriculo temporal branch
5th. infra-orbital branch
5th. inferior dental branch
Superficial cervical (cervical plexus)

PLATE VIII.

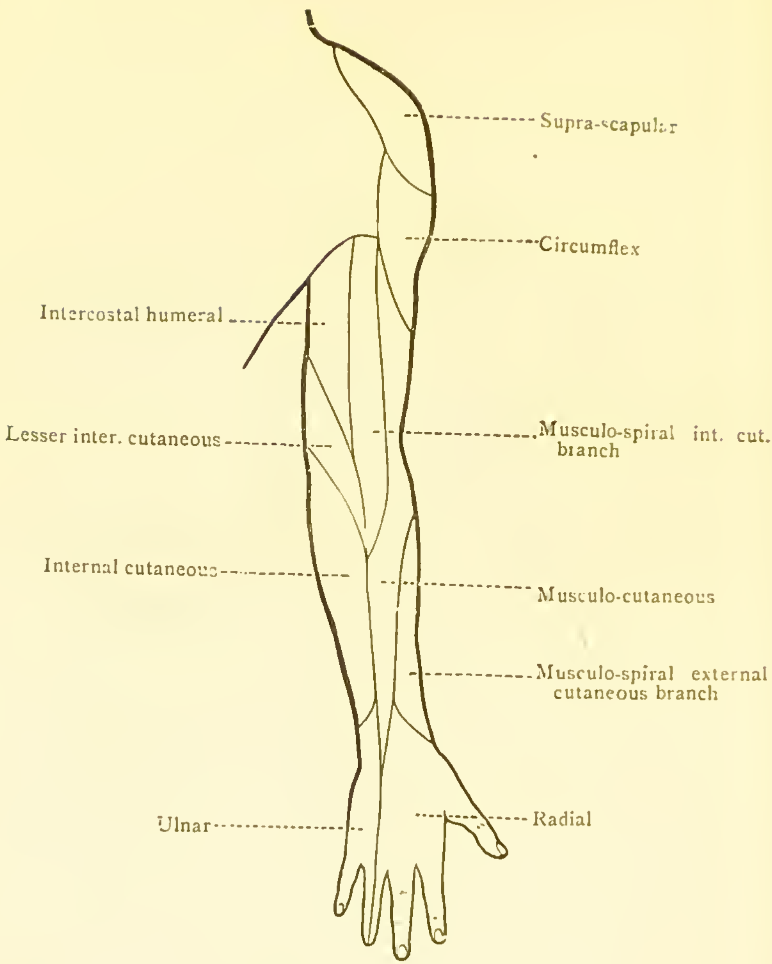
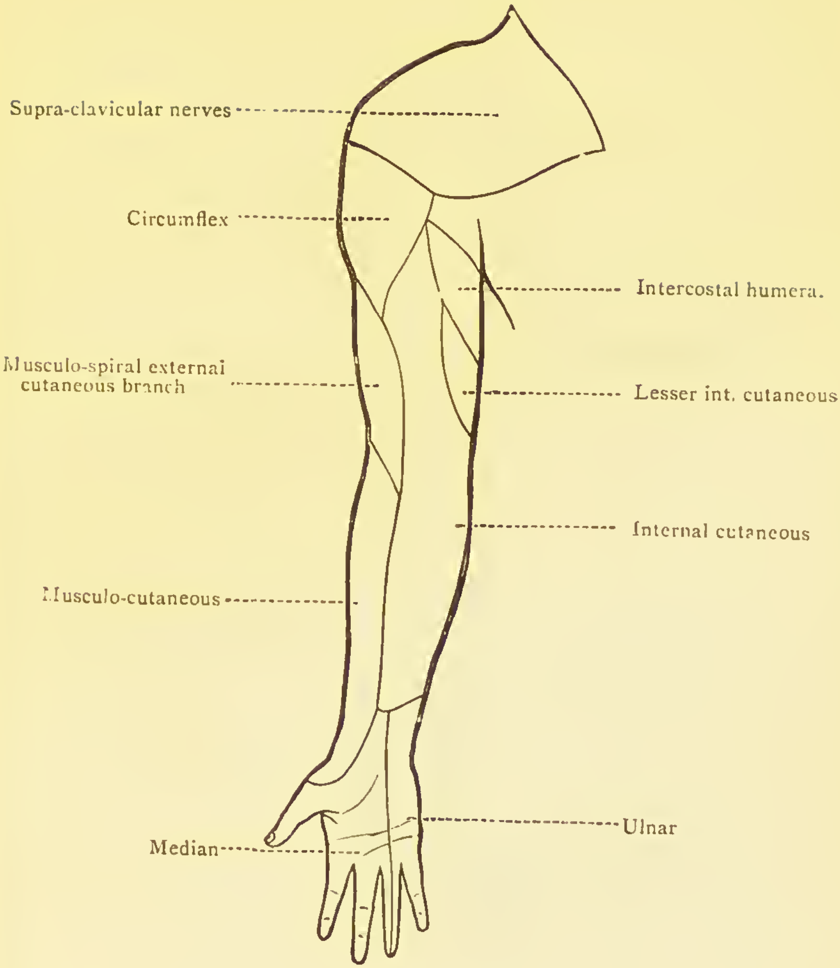
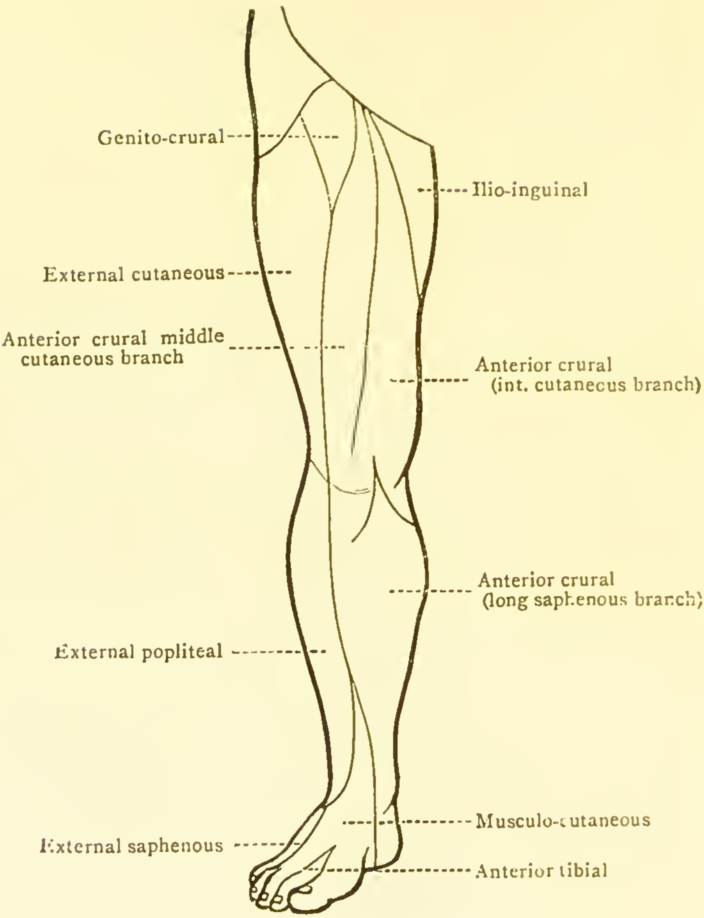

Supra-scapular
Circumflex
Intercostal humeral
Lesser inter. cutaneous
Musculo-spiral int. cut. branch
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Ulnar
Radial

PLATE IX.



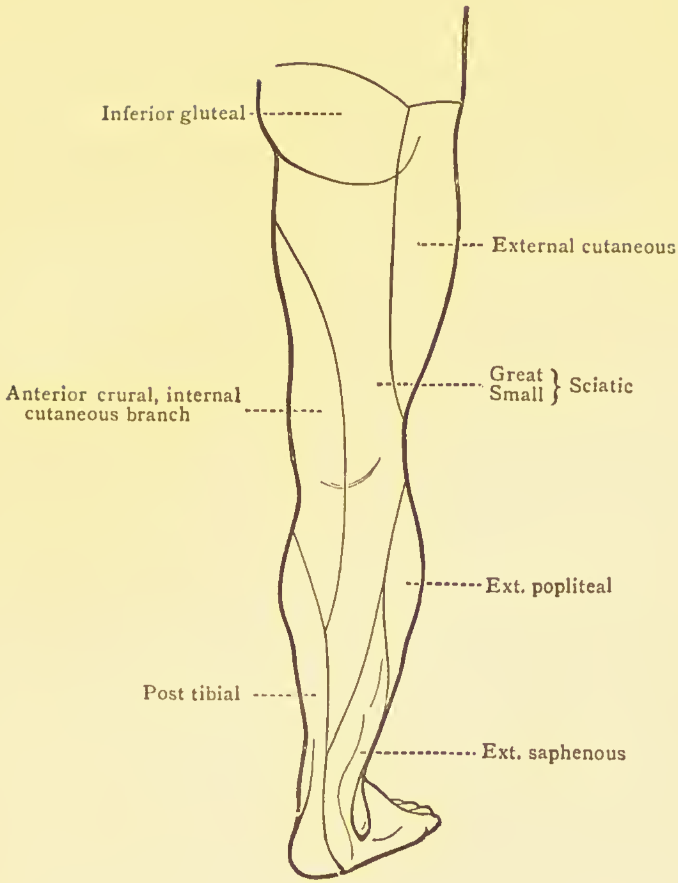
Supra-clavicular nerves
Circumflex
Intercostal humeral.
Musculo-spiral external cutaneous branch
Lesser int. cutaneous
Internal cutaneous
Musculo-cutaneous
Ulnar
Median

PLATE X.



Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI.



Inferior gluteal
External cutaneous
Great
Small
Sciatic
Anterior crural, internal cutaneous branch
Ext. popliteal
Post tibial
Ext. saphenous

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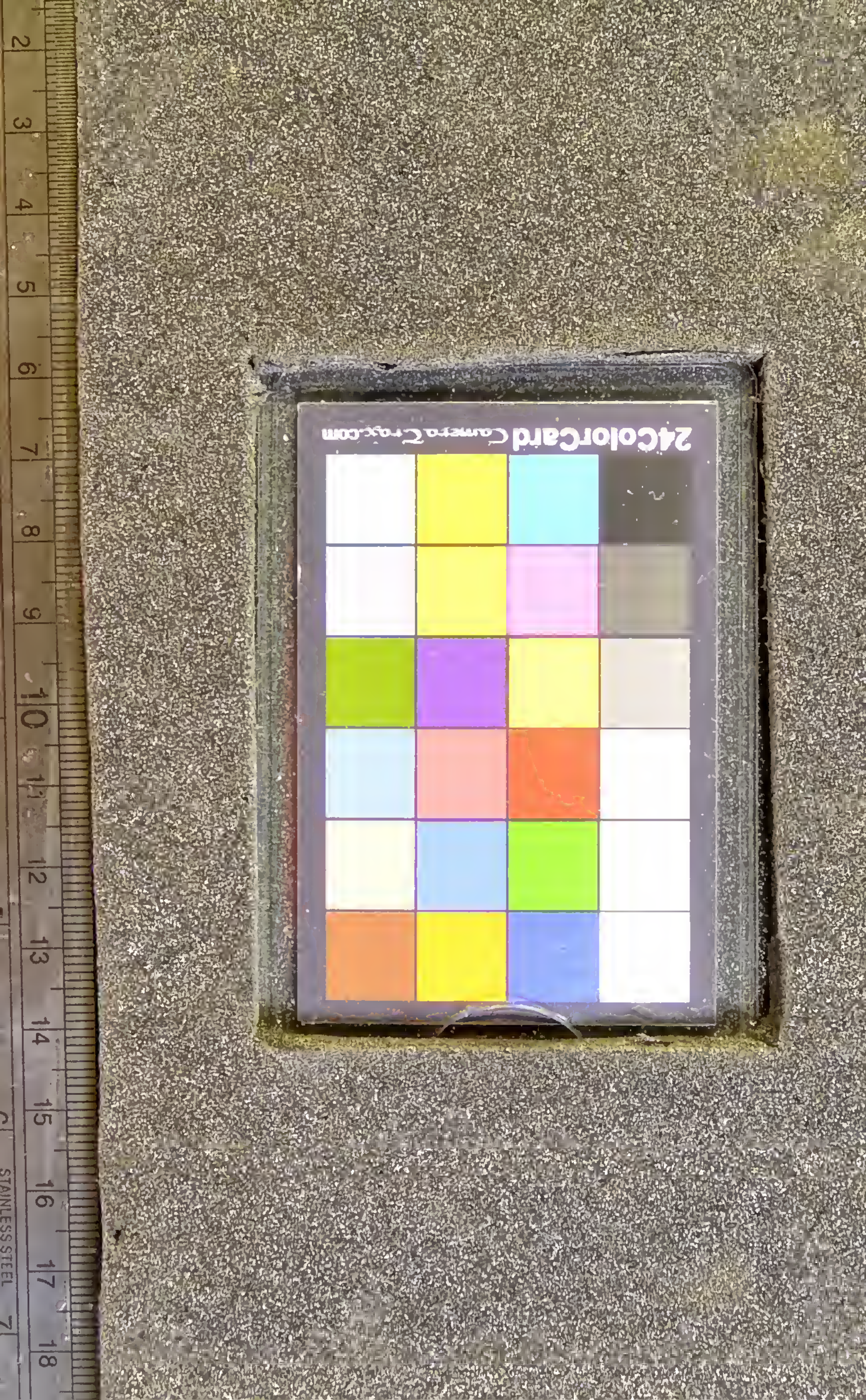
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